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Munition Crush Tests in Support of the Navy's High Performance Magazine Program

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13. ABSTRACT *(Maximum 200 words)*

The U.S. Navy has currently undertaken a task to improve the design of their land-based ammunition magazines. This effort is part of the Navy High Performance Magazine Program. One of the improvements sought in this task is to prevent ammunition in one cell or bay from being sympathetically detonated by rounds which are detonated in an adjacent bay. One of the means by which this sympathetic detonation can occur is the process of crushing of ammunition by the interior walls of the magazine. The interior walls are propelled into the adjacent bay by the force of the explosion in the bay containing the first initiated ammunition.

To determine the conditions under which such a wall can initiate ammunition, ARL has conducted experiments to determine the onset of various types of ammunition reactions when crushed by specially designed moving crush packages and flyer plates. In particular, ARL has conducted experiments to determine the reaction of thin-walled and thick-walled warheads to crushing. By knowing the parameters such as kinetic energy or impulse required to produce certain levels of reaction in ammunition, one can effectively design the internal walls of the magazine and determine the amount of ammunition which can be safely stored in each bay.

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sympathetic denotation, crush test, M107, TOW 2 warhead, PVDF stress gauge, Navy High Performance Magazine Program, flyer plates

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1. INTRODUCTION

The Naval Facilities Engineering Service Center (NFESC) has been conducting experiments and analytical calculations to determine design criteria to prevent sympathetic detonations in the Navy's High Performance Magazine. Ammunition in this magazine is segregated in compartments separated by special walls. If the ammunition in one compartment detonates, the wall will be driven into the adjacent compartment, possibly causing the ammunition in that compartment to detonate. The walls of the magazine are made of a special high porosity concrete that should minimize the shock loading on acceptors. Therefore, the acceptors are more likely to detonate because of crushing than due to high-frequency shock when impacted and crushed by a compartment wall that is constructed of a porous material. This is why NFESC was interested in the initiation of the acceptors by crushing.

The Explosives Technology Branch of the Weapons Technology Directorate of the U.S. Army Research Laboratory was contracted to support NFESC by performing crush tests on thin-walled and thick-walled warheads. These tests were conducted to help the Naval Facilities Engineering Center determine criteria under which these types of munitions detonate when crushed by an internal magazine wall. TOW 2 warheads were used as an example of lightly cased warheads, and 155-mm artillery rounds (M107s) were used as an example of heavily cased warheads. Two flyer plate thicknesses (3.8 and 11.0 cm) were used against the TOW 2 warheads, while three flyer plate thicknesses (3.8, 11.0, and 17.8 cm) were used against the M107s. Flyer plate velocities at which no reaction (no go), burn, explosion, and detonation events occur were obtained for both warheads.

2. OBJECTIVE

The primary purpose of this effort is to provide experimental data on the critical impact condition between a flyer plate and warhead that occur at the transition between reaction (detonation or explosion) and no reaction for typical thick-walled and thin-walled munitions. Some of the reaction criteria being investigated are: case deformation (Δ D), peak shock pressure, momentum of the flyer plate, kinetic energy (KE) of the flyer plate, and velocity of the flyer plate. By knowing the critical conditions at which reactions occur, the Navy will be able to determine whether or not they can prevent sympathetic detonations in the High Performance Magazine.

3. APPROACH

To simulate the magazine walls of the High Performance Magazine, an explosively launched steel flyer plate was used. This flyer plate impacts and exerts a compressive force on a crush package that was placed against the side of the round. The round has the crush package on the side facing the incoming flyer plate and is held in place on the opposite side by an anvil plate. The incoming flyer plate crushes the crush package and round against the anvil plate. The crush package mechanically filters out the shock due to impact just like the magazine wall, hence enabling a crush test to be performed.

4. EXPERIMENTAL SETUP

Figures 1 and 2 show top and side views of the test fixture. The test fixture is comprised of interlocking 11.0-cm-thick rolled homogeneous armor (RHA) plates. The anvil plate, baseplate protector, and witness plate are designed to be removable from the test fixture. To ensure a rigid boundary condition between the round and anvil, the anvil was kept in place by a backstop that is composed of three 183.0-cm × 183.0-cm × 11.0-cm-thick armor plates. Gusset beams were used to help keep the backstop from rotating, and the last 11.0-cm-thick backstop plate was keyed into the baseplate to minimize horizontal translation. The two frame catcher plates are braced by U-shaped stiffeners that fit over the frame catchers and are welded to the baseplate. Slight modifications to the test fixture were made during the test series to try to fix weaknesses found in the fixture. Figure 3 shows a photograph of the test fixture. Figure 4 shows an M107 round placed in the test fixture prior to setting up the crush package.

A crush package of five polyethylene and four steel plates was used (see Figure 5). The plates are 45.0 cm wide, 76.2 cm high, and 2.54 cm thick. The layer closest to the flyer plate was polyethylene and contained the inserts for the piezopins. The layer closest to the round was also polyethylene. This type of crush package has been shown to be a good mechanical filter for minimizing the high frequency content of the impulse that the flyer plate creates when compacting the round, Starkenberg (1987). This enables us to perform a crushing test while minimizing the shock effects of impact. It is believed that the barrier walls designed for the High Performance Magazine Program will exhibit similar mechanical filtering characteristics as the crush package used in this test.

Data for peak shock pressure were to be derived from measurements obtained by a 3.2-mm × 3.2-mm × 0.025-mm polyvinylidene fluoride (PVDF) gauge mounted between the round and the anvil

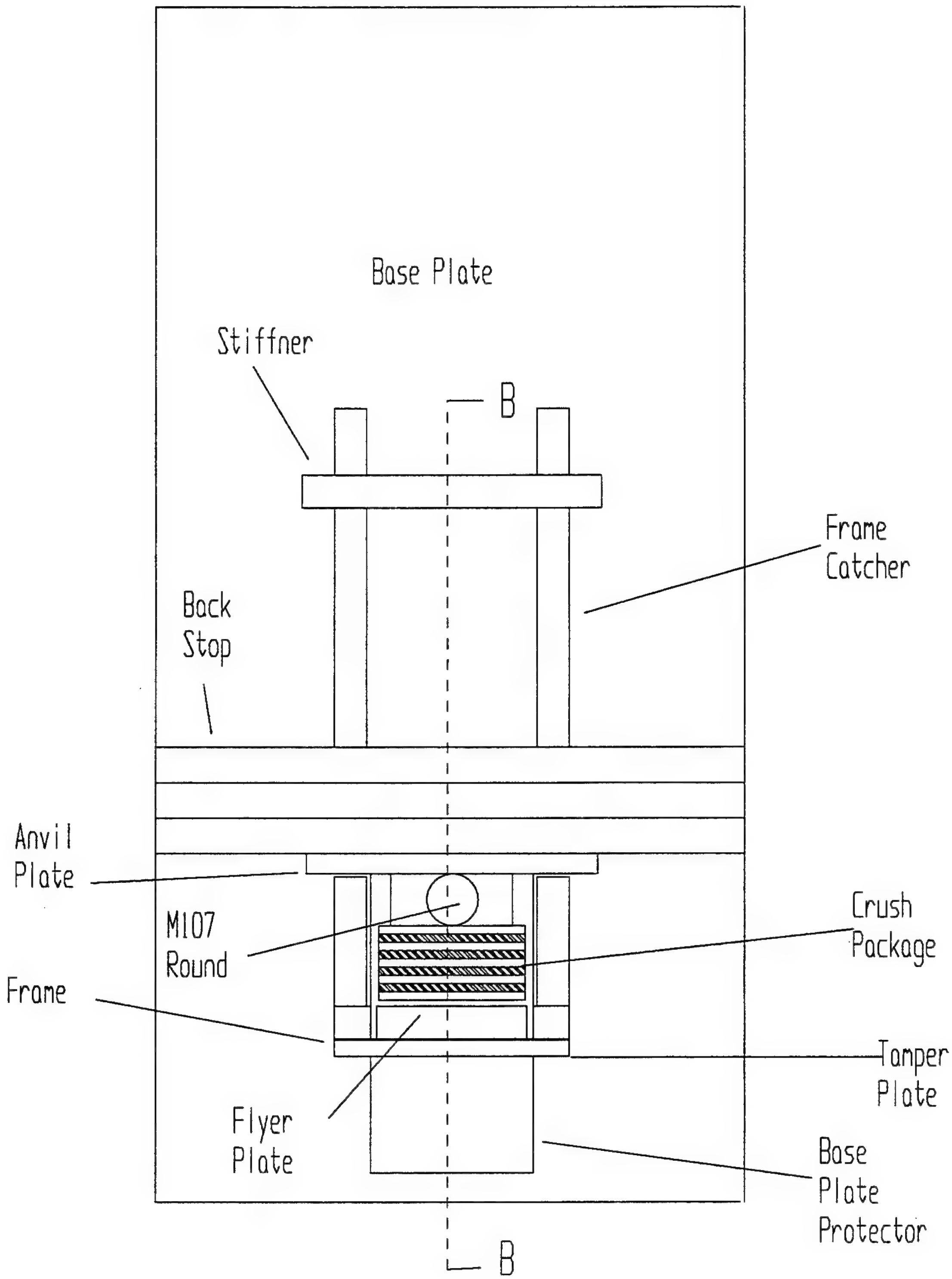

Figure 1. Schematic of top view of the test fixture.

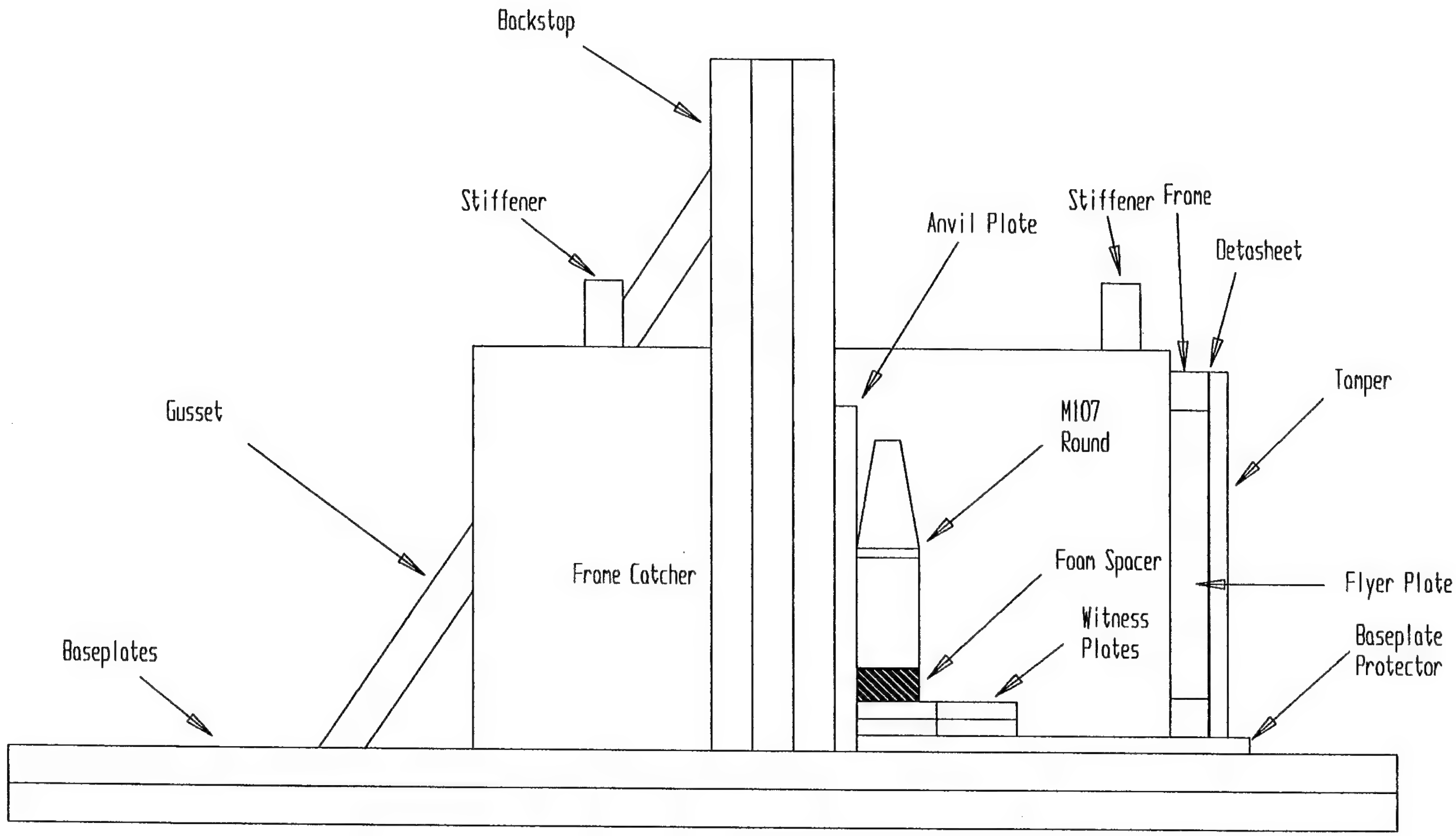

Figure 2. <u>Section B-B of test fixture schematic.</u>

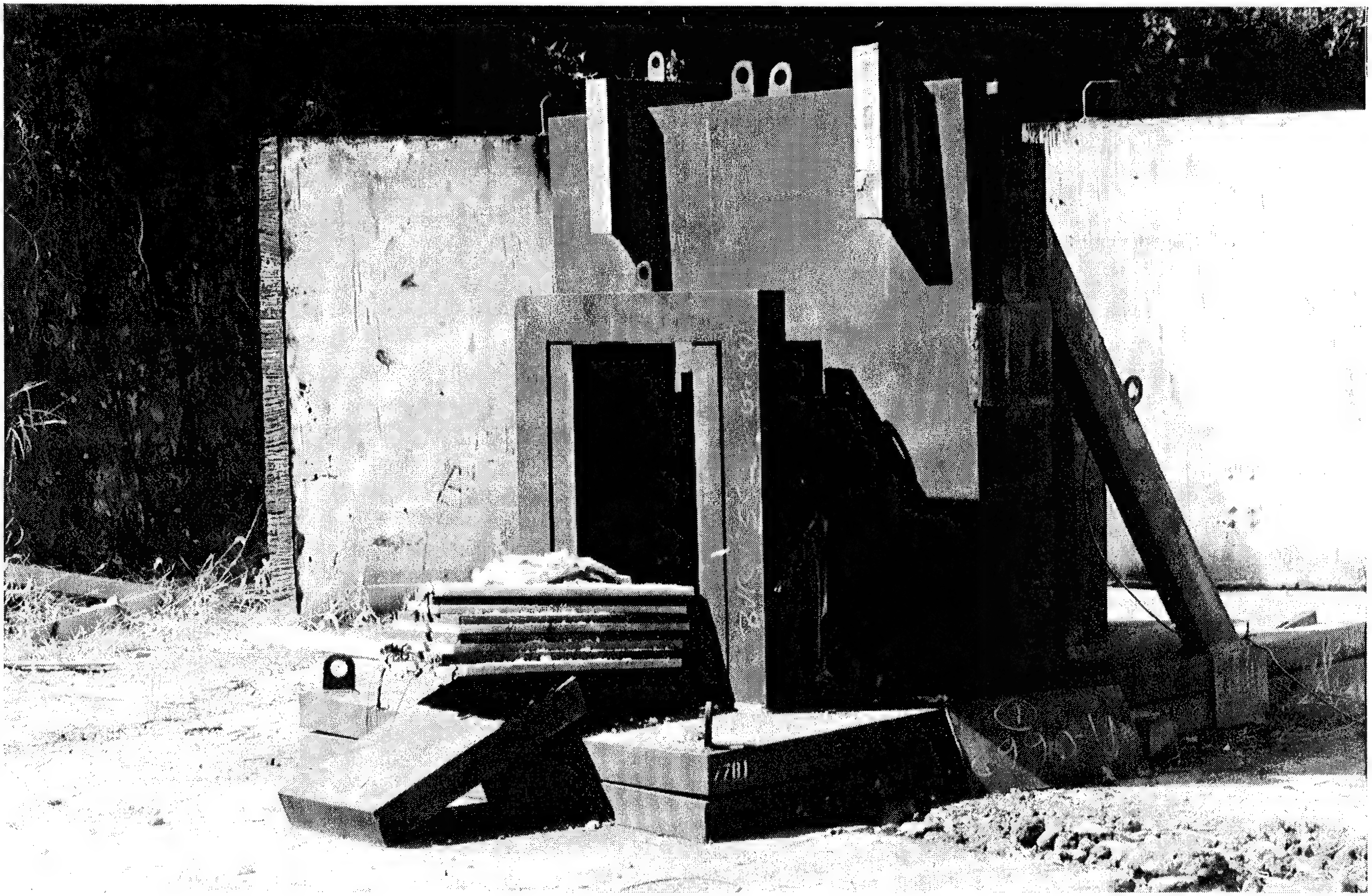

Figure 3. Photograph of test fixture.

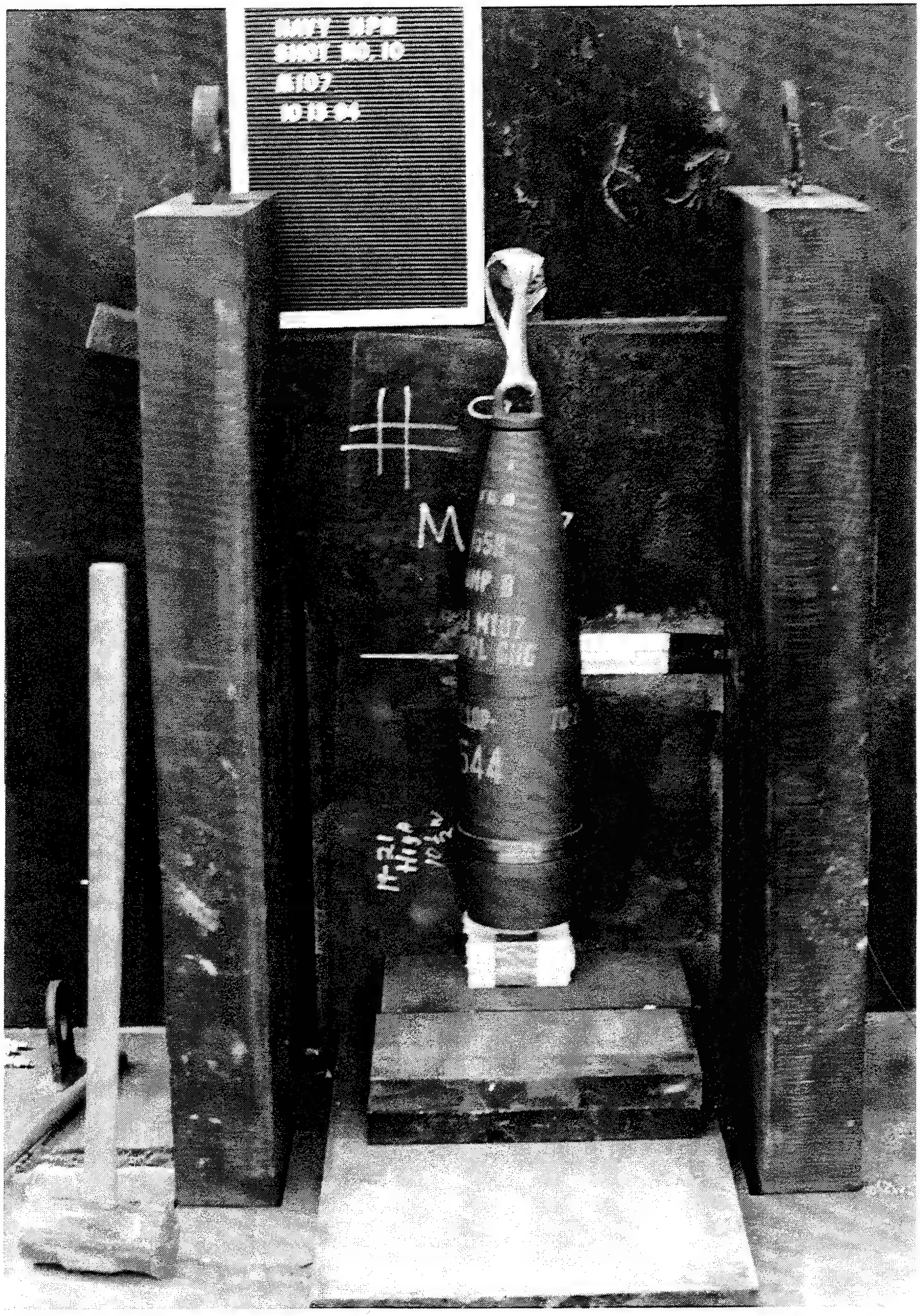

Figure 4. <u>Front view of the test fixture with M107 round in place</u>.

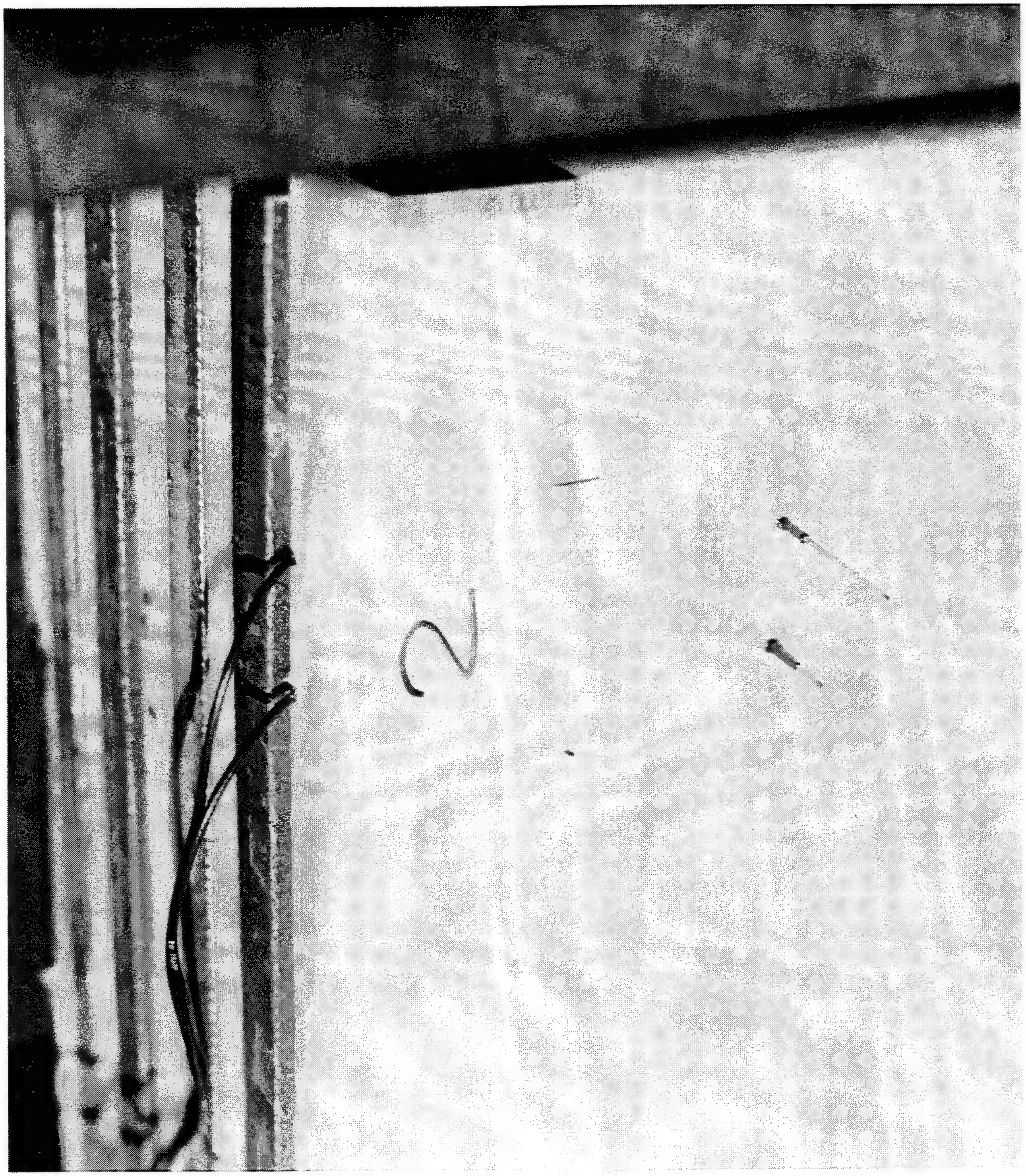

Figure 5. Crush package with piezoelectric pin insert.

plate. The PVDF gauge was covered by a thin aluminum foil. The small size of the gauge and the thin cover was judged to provide conditions which were virtually indistinguishable from a bare RHA anvil plate as far as initiation of any reaction in the munition. The particular PVDF gauge used in this test could measure pressures up to 250 kbar while maintaining a response time of approximately 10 ns.

The PVDF gauge was placed on the anvil plate so that it would contact the round near the transition from the ogive to the main body of the M107 round. It should be noted that to keep this region (called the bourrelet) flush with the anvil plate, and in constant contact with the PVDF gauge, and to keep the top portion of the round from smacking the anvil plate, the round was tilted on a spacer so that the bourrelet and rotating band were always flush with the anvil plate (see Figure A-1). The round was usually tilted approximately 2° to maintain contact with the anvil. This means that there are initially two load paths between the anvil plate and the round. However, the anvil was only instrumented where it was in contact with the bourrelet of the round due to cost considerations. This meant that the data obtained would be qualitative, not quantitative, of the maximum pressures and durations of the interface pressure between the round and anvil plate.

The PVDF gauges were bonded to the anvil plate using standard strain gauge bonding techniques. Micro Measurements A-10 and GA-2 adhesives were used to bond the gauge to the anvil plate. In initial tests, coaxial cable was attached directly to the PVDF gauge. However, solder joints were exposed more easily to the deformation of the round due to the solder joint size and because the gauge's lead length that was selected was too short for the deformations that were experienced by the rounds. Because of this problem, it was decided to use 134-AWP wire from Micro Measurements to run from the PVDF gauge to solder tabs that were situated in a location that was unlikely to be damaged during the reaction. The coaxial cable was then attached to the solder tab. This solution causes several problems. It creates an impedance mismatch in the PVDF circuitry and makes the circuitry more susceptible to extraneous noise from the electric bridge wire detonator and explosive products from the Detasheet. Although problems were introduced by this wiring procedure, data could be sampled for approximately 20 ms in a number of tests before lead/gauge failure. The signal conditioning for the PVDF consisted of a charge integrator by Dynasen Inc., and a buffer circuit fabricated at ARL. The circuitry's cutoff frequency was 7.8 Hz and had a time constant of approximately 20 ms. The primary purpose for the buffer circuit was to allow the use of cable runs over 150 m long without cable induced distortions of the signal. The specifications mentioned previously for the signal conditioning circuitry are for the final version of the signal conditioning circuitry used. Signal conditioning was developed and adjusted on the TOW 2 warhead crush tests and was finalized by the time the M107 tests were started.

Flyer plate velocities were measured by using four 1.6-mm-diameter piezoelectric pins mounted in the polyethylene layer next to the flyer plate (see Figure 5). Removable rectangular cutouts in this first polyethylene layer were used to mount the piezoelectric pins (see Figure 6). The piezoelectric pin/rectangular cutout assembly was constructed and then measured in an optical comparator (to obtain accurate velocity measurements) before being inserted into the first polyethylene layer. Coaxial cabling was used with the piezoelectric pins to minimize extraneous noise. Two pretests were conducted in which a single bridge wire RP80 detonator was detonated to check EMF levels in the instrumentation circuits.

In tests where flyer plate velocities were below 30 m/s, make switches were used in conjunction with piezopins. Make switches consisted of single-pole, single-throw momentary pushbutton switches mounted in the removable rectangular cutouts that are positioned in the polyethylene layer next to the flyer plate. Two switches were used together. One switch was placed 5 cm closer to the incoming flyer plate than the second switch so that velocity measurements could be obtained. As the flyer plate impacts the switch, the switch opens causing a change in voltage that can be measured by an oscilloscope. Knowing the times of impact recorded by the oscilloscope and the separation of the switches, a flyer plate velocity can be calculated. Make switches are not as accurate as the piezoelectric pins and, therefore, were only used at low velocities where it was difficult to obtain piezoelectric pin data.

The Gurney equation for an asymmetric plate was used to determine the amount of HE and the proper tamper plate size required to launch the flyer plate at the planned velocities. See equations 1, 2, and 3 and Figure 7.

$$V_M = \sqrt{2E}\left[\frac{1 + A^3}{3(1 + A)} + \frac{N}{C}A^2 + \frac{M}{C}\right]^{-1/2} \tag{1}$$

$$A = \frac{1 + 2\frac{M}{C}}{1 + 2\frac{N}{C}} \tag{2}$$

$$V_N = AV_M \tag{3}$$

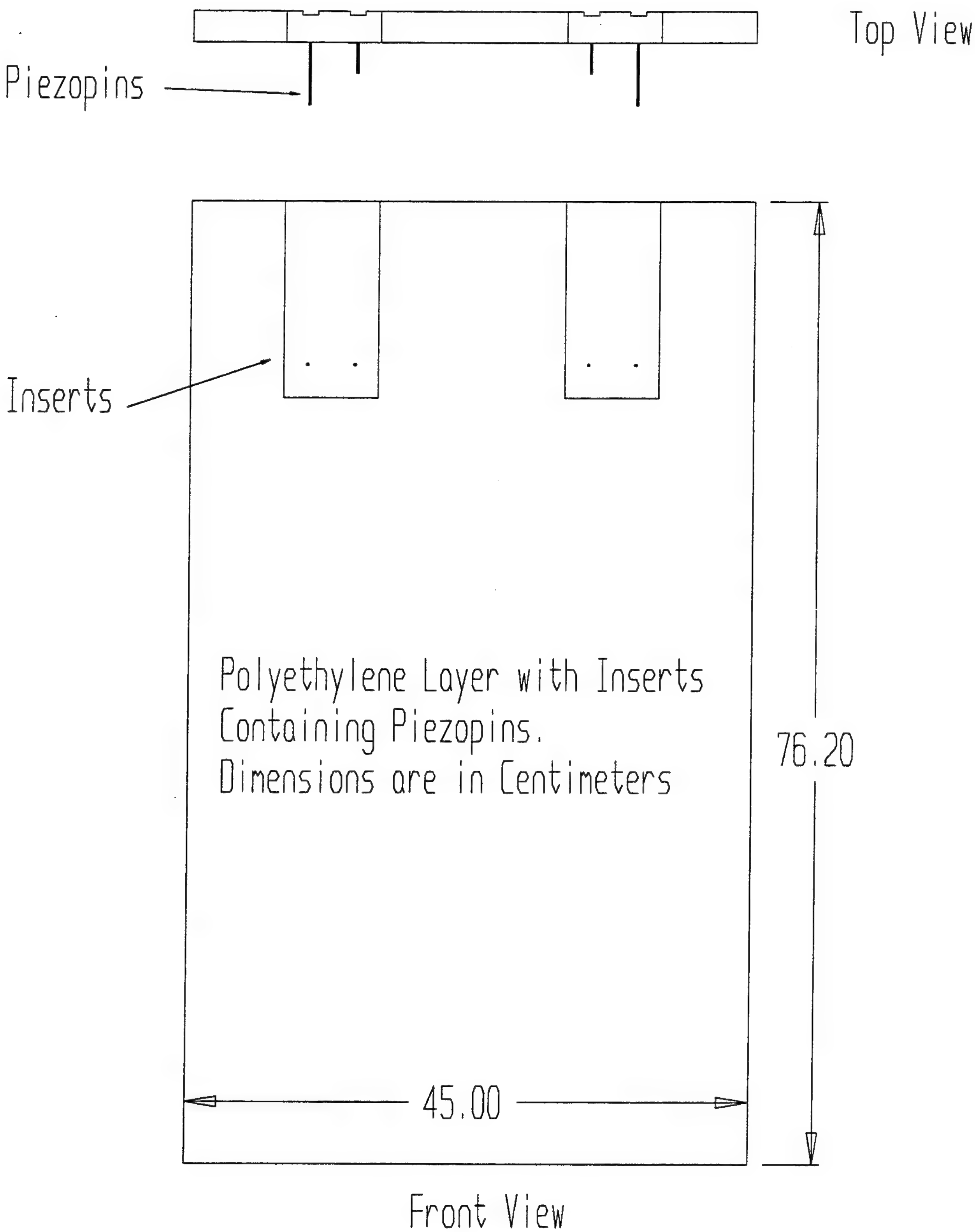

Figure 6. Schematic of piezoelectric pin insert inside of first polyethylene layer.

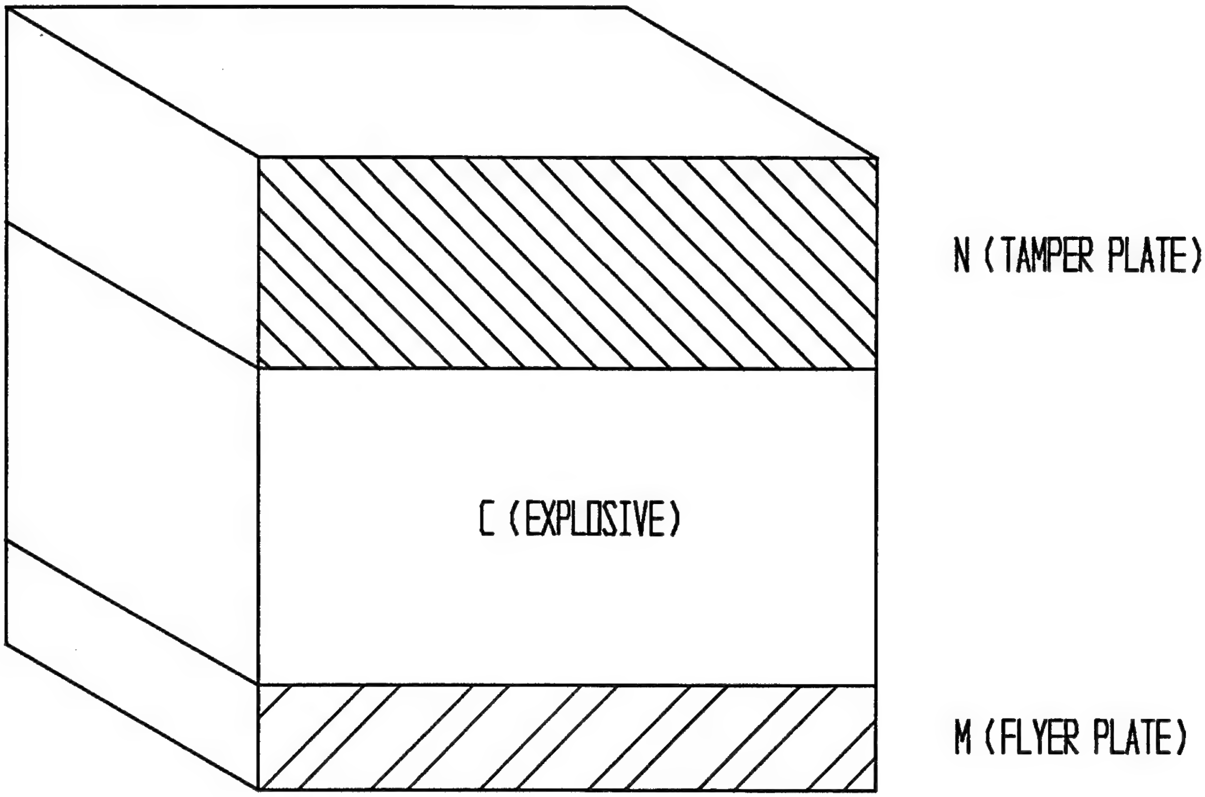

Figure 7. Asymmetric flyer plate sandwich.

The variables in the Gurney equations are defined as follows: C = mass per unit area of explosive, N = mass per unit area of tamper, M = mass per unit area of flyer plate, V_M = terminal velocity of flyer plate, V_N = terminal velocity of tamper plate, E = Gurney specific energy. An assumption used in the Gurney equation is that potential energy of the explosive is converted directly into KE of the plates after detonation and to the expansion of explosive products. These equations have been found to agree very well with measured experimental flyer plate velocities.

Witness plates and an anvil plate (3.8 cm thick) were used to distinguish between a detonation and an explosion. Pictures of the witness and anvil plates were taken for shots in which a detonation occurred.

Data to verify the case deformation criteria (Δ D) were supplied by measuring the change in diameter of the round at various locations along the length of the round after impact using photographic techniques and direct measurements. Photographs were taken from selected views to allow comparison between reported numerical data and actual round deformations.

A total of 20 shots were performed from September 1994 through December 1994. Twelve of these shots were conducted using M107s. The other eight shots were performed on TOW 2 warheads. Steel flyer plates of 3.8-cm and 11.0-cm thicknesses were used in the TOW 2 warhead tests. In the M107 crush tests, 3.8-, 11.0- and 17.8-cm-thick flyer plates were used. Four different momentum levels were planned to be used in the tests for both warheads. The flyer plates used were 45.0 cm wide and 76.2 cm high. The flyer plates were enclosed by a frame with overall dimensions of 61.0 cm by 91.0 cm. The frames were used to minimize edge effects. The rounds were elevated on foam blocks to ensure that the rounds were centered in the flight path of the center of the flyer plate.

Table 1 shows the initial test matrix for the M107. This test matrix is called initial because the test matrix was modified by the results obtained during testing to best close in on the conditions that occur at the transition between no reaction and reaction (explosion or detonation). The baseline for the M107 test series was the 45.0-cm × 76.2-cm × 11.0-cm flyer plate with a velocity of 95 m/s. In previous work performed by Lyman (1994), the same conditions yielded no reaction (no go) in the M107. Upon verifying a no go for our test setup, the momentum was to be kept the same but repeated with the 3.8-cm-thick flyer plate and the 17.8-cm-thick flyer plate with the appropriate velocities as shown in Table 1. From this planned series of tests, an initial confirmation of a constant momentum criteria for reaction could be made.

Table 1. Initial Test Matrix for M107 Crush Tests

	V1	V2	V3	V4
3.8-cm Flyer	P = 28,700 K = 3.4 V = 237	P = 35,200 K = 5.1 V = 291	P = 40,700 K = 6.8 V = 336	P = 49,800 K = 10.2 V = 411
11.0-cm Flyer	P = 28,700 K = 1.3 V = 95	P = 35,200 K = 2.0 V = 116	P = 40,700 K = 2.7 V = 134	P = 49,800 K = 4.1 V = 164
17.8-cm Flyer	P = 28,700 K = 0.8 V = 59	P = 35,200 K = 1.3 V = 73	P = 40,700 K = 1.7 V = 84	P = 49,800 K = 2.5 V = 103

Units: P = kg * m/s; K = MJ; V = m/s
Each column provides impact conditions at constant momentum.

The initial plan was that the next test would again use the 11.0-cm-thick flyer but with a velocity of 134 m/s, a momentum of 40,700 kg m/s and would have twice the initial KE of the previous 11.0 cm flyer test. If an explosion or detonation occurred, then the next tests planned would have the same momentum but would have used the 3.8-cm and the 17.8-cm flyer plates. From this point on, the test conditions were to be adjusted to close in on the transition conditions, while checking to see if constant momentum criterion was valid.

Since previous data were not available for the TOW 2 warhead, data from tests conducted by Lyman (1994) on TOW 2 flight motors were used to give an estimate as to the velocity ranges with which to start. Table 2 shows the initial test matrix for the TOW 2 warhead tests. Again, an adaptive test procedure was used to close in on the transition point between reaction and no reaction.

Table 2. Initial Test Matrix for TOW II Warhead Crush Tests

	V1	V2	V4	V5
3.8-cm Flyer	P = 21,200 K = 1.8 V = 175	P = 30,000 K = 3.7 V = 247	P = 36,700 K = 5.5 V = 303	P = 42,400 K = 7.4 V = 350
11.0-cm Flyer	P = 21,200 K = 0.7 V = 70	P = 30,000 K = 1.4 V = 99	P = 36,700 K = 2.2 V = 121	P = 42,400 K = 2.9 V = 140

Units: P = kg * m/s; K = MJ; V = m/s
Each column provides impact conditions at constant momentum.

5. RESULTS

A total of 23 tests were performed. Eight of these tests were conducted on TOW 2 warheads, 11 tests were conducted on M107s, and 4 tests were practice shots to troubleshoot problems that occurred when using the 17.8-cm flyer plates.

The piezoelectric pin inserts used in the crush tests worked about 60% of the time. In the TOW 2 warhead tests, no tamper plate was used and data were obtained for all the tests except for the first two tests where improper termination was used. For the M107 tests, tamper plates were used. The use of tamper plates increases the blast effects that are sensed by the piezoelectric pins. Some tests showed

evidence that the blast wave would cause the first polyethylene plate in the crush package to oscillate against the first metal plate, causing the piezoelectric pins to produce extraneous signals that would make it difficult to detect the impact of the flyer plate. A thin layer of isodamp (2 mm thick) was placed between the first polyethylene plate and the first steel plate to try to damp out these extraneous signals. This layer of isodamp worked well in cases where the flyer plate velocity was fairly fast (70 m/s and up). In tests where the flyer plate velocity was low, the isodamp had to be removed because it was damping out the signal of the impact too much relative to the extraneous noise. In the first tests of the 17.8-cm thick flyer, no velocity data was obtained due to the slow speed of the flyer plate. Make switches were used in offline tests to obtain the velocity for this first 17.8-cm flyer plate test. It was noticed during testing, that when using Detasheet with a thickness of 5 mm and below, good velocity measurements were obtained from the piezoelectric pins. If larger diameter piezoelectric pins had been used, better velocity data may have been obtained.

Reaction levels were determined using MIL-STD-2105A (NAVY) as a guide. Physical evidence such as the damage to the witness and anvil plates was used to distinguish between explosion and detonation events. No go/burn reactions could be classified as partial burns, while explosion/detonation events could be classified as partial detonation events as described by MIL-STD-2105A. Burn/explosion events are explosion events where fragments show char marks or burnt residue that would indicate that the explosive may have been burning prior to developing into an explosion.

5.1 <u>TOW 2 Warhead Crush Tests</u>. Two flyer plate thicknesses were used for the TOW 2 warhead crush tests (3.8 and 11.0 cm). For the 3.8-cm-thick flyer plate tests, two no go, one no go/partial burn, and one detonation reaction were obtained. For the 11.0-cm-thick flyer plate tests, one no go, one vigorous burn, one explosion/detonation, and one detonation reaction occurred. Table 3 summarizes the flyer plate velocity, momentum, KE, test temperature and resulting reaction for each test conducted. Figures 8, 9, and 10 show resulting reaction vs. flyer plate velocity, momentum, and KE, respectively. The ordinate reaction values in these figures for the various resulting reactions are as follows, detonation (4), detonation/explosion (3.5), explosion (3), burn/explosion (2.5), burn (2), no go/partial burn (1.5), and no go (1). Comparing these three figures reveals that the closest agreement between the two flyer plates occurs for a KE relationship. Though this data does not definitely prove that a KE relation is the sole criterion for reaction, the data does show that it follows fairly close. In Figure 10, one notices that the detonation occurring for the 11.0-cm flyer plate has a much larger KE than the KE occurring for the

Table 3. Final Results for TOW 2 Warhead Crush Tests

3.8-cm-Thick Flyer Plate Mass = 104 kg	Velocity = 34.5 m/s Momentum = 3,500 KE = 61.8 Result = No Go Test No. 5 Temp. = 11.5° C	Velocity = 48 m/s Momentum = 4,900 KE = 119.8 Result = No Go Test No. 6 Temp. = 11.5° C	Velocity = 54 m/s Momentum = 5,600 KE = 151.6 Result = No Go/Burn Test No. 7 Temp. = 14.3° C	Velocity = 63.8 m/s Momentum = 6,600 KE = 212 Result = Detonation Test No. 4 Temp. = 13.6° C
11.0-cm-Thick Flyer Plate Mass = 303 kg	Velocity = 25.7 m/s Momentum = 7,700 KE = 100 Result = No Go Test No. 3 Temp. = 16.9° C	Velocity = 28.6 m/s Momentum = 8,600 KE = 124 Result = Vigorous Burn Test No. 8 Temp. = 17.8° C	Velocity = 38 m/s Momentum = 11,500 KE = 218 Result = Det/Exp Test No. 2 Temp. = 21.0° C	Velocity = 70 m/s Momentum = 21,200 KE = 742 Result = Detonation Test No. 1 Temp. 23.8° C

Units: Momentum = kg * m/s, KE = kJ (kilojoules)
All velocity data were obtained from experiments except for test no. 1 and test no. 2. The piezoelectric pins were attenuated too much in test no. 1 and test no. 2.

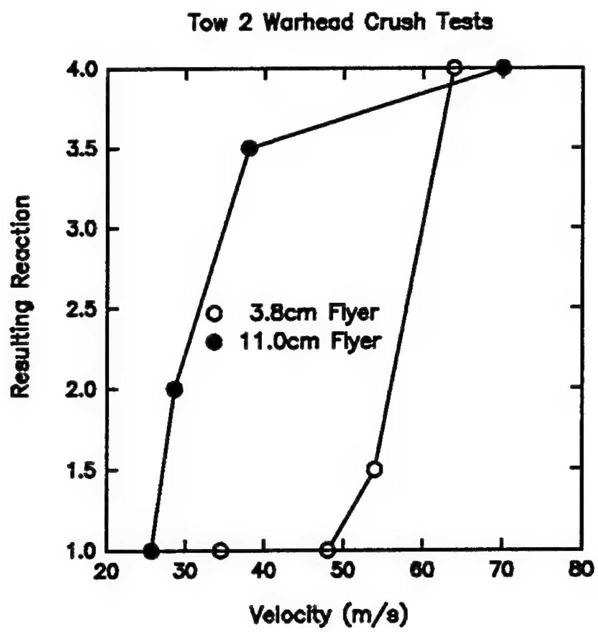

Figure 8. Plot of resulting reaction vs. flyer plate velocity for TOW 2 warhead crush tests.

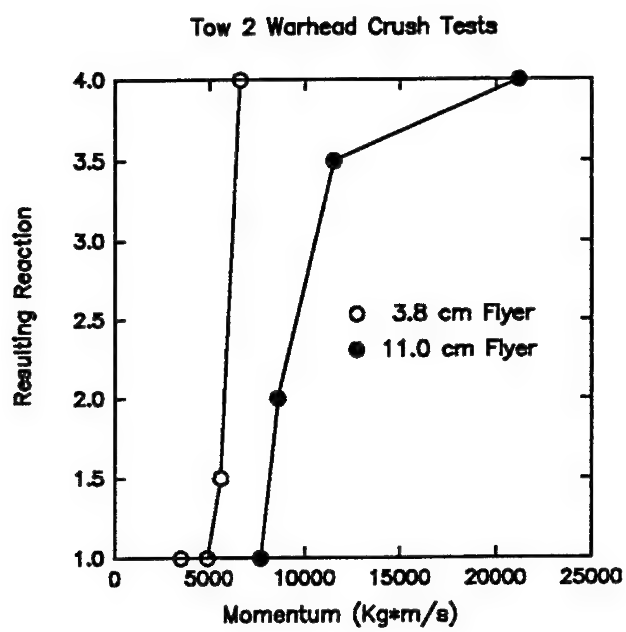

Figure 9. Plot of resulting reaction vs. flyer plate momentum for TOW 2 warhead crush tests.

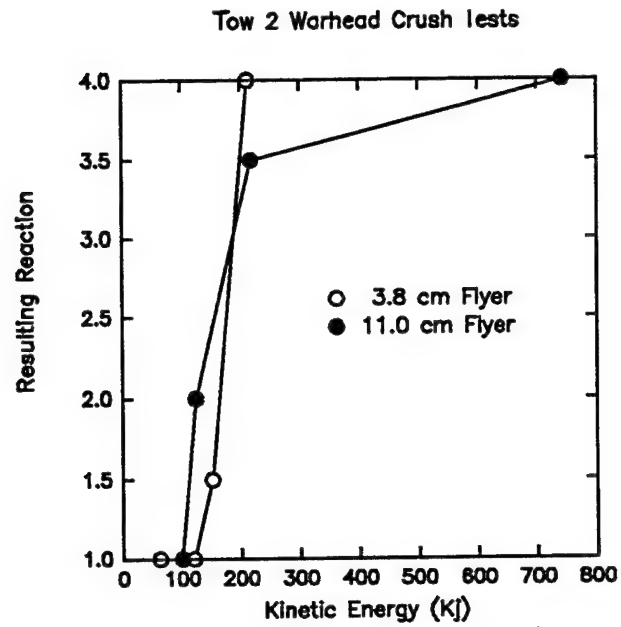

Figure 10. Plot of resulting reaction vs. flyer plate KE for TOW 2 warhead crush tests.

3.8-cm flyer plate. This large difference in KE is because the test for the 11.0-cm flyer (test no. 1) was an over test. The initial conditions for this test were based on results of testing by Lyman (1994) on TOW 2 flight motors. The presupposition was that the TOW 2 flight motor had similar sensitivities to the TOW 2 warhead or that the flight motor was slightly more sensitive. Unfortunately, the flyer plates used in this work turned out to be approximately three times as massive as the ones used by Lyman (1994), hence test no. 1 was a detonation reaction for the warhead; whereas, Lyman (1994) had a burn reaction for the flight motor at this test condition. If additional tests had been conducted, we believe we would have been able to show closer correlation between the KE of the two flyer plates at which a detonation occurs.

Figure 11 shows typical deformation that occurred to the TOW 2 warheads in a no go event. It can be noticed in this figure that the side case wall cracks and elastically rebounds during crushing; whereas, the copper liner is plastically deformed. The copper cone, therefore, is a better guide in determining the amount of deformation that the round underwent. In tests where no go or burn events occurred, the round was broken into two primary parts: the main casing which included the copper cone and the body loading assembly. In Figure 12, a photograph of the rear portion of the body loading assembly is shown after being crushed.

Figure 11. Top view of TOW 2 warhead after being crushed in a no go test.

Figure 12. View of rear part of body loading assembly of TOW 2 after a crush test.

5.2 M107 Crush Tests. Three flyer plate thicknesses were used in the M107 crush tests (3.8, 11.0, and 17.8 cm). For the 3.8-cm flyer plate, one no go, one no go/partial burn, one burn/explosion, and one detonation reaction were obtained. Three tests were conducted using the 11.0-cm-thick flyer plate which included one no go, one burn/explosion, and one detonation reaction. Finally, for the 17.8-cm-thick flyer plate, the following reactions were obtained; two no go, one no go/partial burn, and one explosion/ detonation reaction. Table 4 summarizes the flyer plate velocity, momentum, KE, test temperature and resulting reaction for each test conducted. Figures 13, 14, and 15 show resulting reaction vs. flyer plate velocity, momentum, and KE, respectively. The values for the various resulting reactions are assigned as follows, detonation (4), detonation/explosion (3.5), explosion (3), burn/explosion (2.5), burn (2), no go/partial burn (1.5), and no go (1). Comparing these three figures reveals that the flyer plate parameter yielding the closest correlation to the test result is the momenta of the flyer plates. A closer correlation exists between the 3.8- and 11.0-cm flyers than with the 17.8-cm flyer. Test no. 17 and test no. 18, which correspond to the two lowest momentum values for the 17.8-cm-thick flyer on Figure 14, are considered to be under test situations. In these tests, velocities of 20 m/s and 45 m/s were obtained for the 17.8-cm flyer plate, which is much lower than the 63 m/s and 71 m/s velocities that were the planned values (computed from the Gurney equation).

Four off-line tests were conducted to allow us to get better control of the flyer plate velocities. Some success was obtained, but we still were not able to control the flyer plate velocities as well as we were with the 3.8- and 11.0-cm flyer plates. The problem of obtaining the desired velocities with the 17.8-cm flyer plate was due to the fact that typical charge to mass ratios for the 17.8-cm flyer were several orders of magnitude lower than the charge to mass limit for obtaining accurate velocities using the Gurney equations, Yadav (1988). Venting of the explosive products was also a primary factor for not obtaining accurate velocity predictions due to the large size of the flyer and tamper plates. Test no. 20 corresponds to the 3.5 reaction value shown for the 17.8-cm flyer in Figure 14. Comparison of this data point with the 3.8- and 11.0-cm flyer plate data indicates that it could be classified as a detonation. Physical evidence from the test made it difficult to classify this reaction. The primary fragments that were found after the test were large compared to what would be expected if a detonation occurred and yet were slightly smaller than fragments recovered from previous explosion reactions. Another factor that made it difficult to classify this test was the amount of damage observed on the anvil plate. In previous tests, where explosions occurred, little or no damage to the anvil plate was found. However, in tests where detonations occurred, distinct plastic deformation occurred on the anvil plate. In test no. 20, the anvil plate was plastically deformed, but not to the same extent as in tests where definite detonations occurred. Because of these results, this test was classified as an explosion/detonation event.

Table 4. Final Results for M107 Crush Tests

3.8-cm-Thick Flyer Plate Mass = 104 kg	Velocity = 250 m/s Momentum = 26,000 KE = 3.25 Result = No Go Test No. 10 Temp. = 14.6° C	Velocity = 330 m/s Momentum = 34,300 KE = 5.66 Result = No Go/ Partial Burn Test No. 12 Temp. = 14.2° C	Velocity = 396 m/s Momentum = 41,100 KE = 8.15 Result = Burn Explosion Test No. 14 Temp. = 15.1° C	Velocity = 433 m/s Momentum = 45,030 KE = 9.75 Result = Detonation Test No. 13 Temp. = 10.8° C
11.0-cm-Thick Flyer Plate Mass = 303 kg	Velocity = 88 m/s Momentum = 26,600 KE = 1.2 Result = No Go Test No. 9 Temp. = 17.8° C	No Test	Velocity = 140 m/s Momentum = 42,400 KE = 2.97 Result = Burn/Explosion Test No. 11 Temp. = 14.6° C	Velocity = 147 m/s Momentum = 44,500 KE = 3.27 Result = Detonation Test No. 15 Temp. 18.4° C
17.8-cm-Thick Flyer Plate Mass = 485 kg	Velocity = 20 m/s Momentum = 9,700 KE = 0.09 Result = No Go Test No. 17 Temp. = 13.2° C	Velocity = 45 m/s Momentum = 21,800 KE = 0.49 Result = No Go Test No. 18 Temp. = 22° C	Velocity = 58 m/s Momentum = 28,100 KE = 0.81 Result = No Go/ Partial Burn Test No. 19 Temp. 6.2° C	Velocity = 93 m/s Momentum = 45,100 KE = 2.09 Result = Exp/Det Test No. 20 Temp. 6.3° C

Units: Momentum = kg 8 m/s, KE = MJ (Megajoules)

1. Experimental velocity data were obtained for shots 9, 15, 17, 19, and 20. Shot 20's velocity data is questionable. Experimental velocity data were obtained for shots 11 and 12, but the pins were placed too close to the flyer plate to obtain a terminal velocity. Gurney velocities were used for shots 10, 13, and 14. Shot 18's velocity was extrapolated from the Gurney velocity and loss percentage calculated from shot 19.

2. Four practice shots (shots 16a, b, c, and 18a) were performed to correct instrumentation problems and to also enable us to get better velocity control with the 17.8-cm flyer plates.

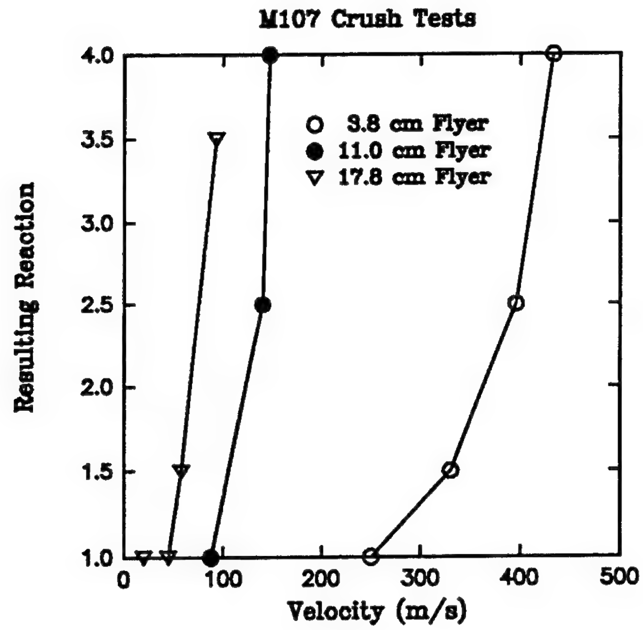

Figure 13. Plot of resulting reaction vs. flyer plate velocity for M107 crush tests.

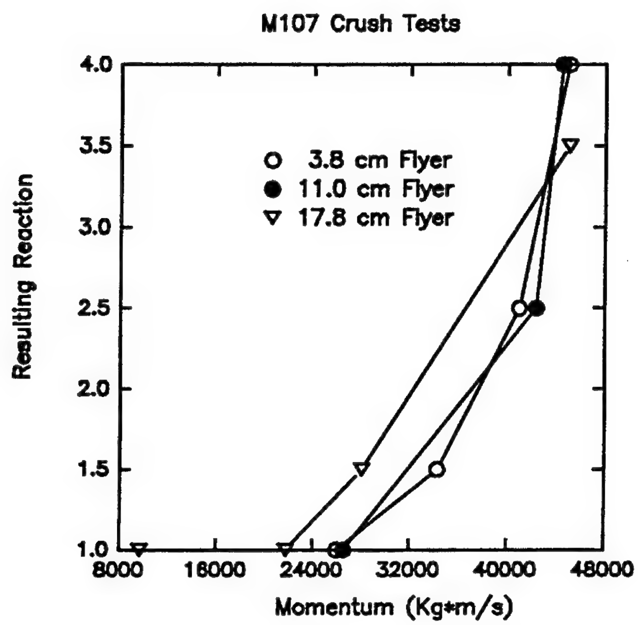

Figure 14. Plot of resulting reaction vs. flyer plate momentum for M107 crush tests.

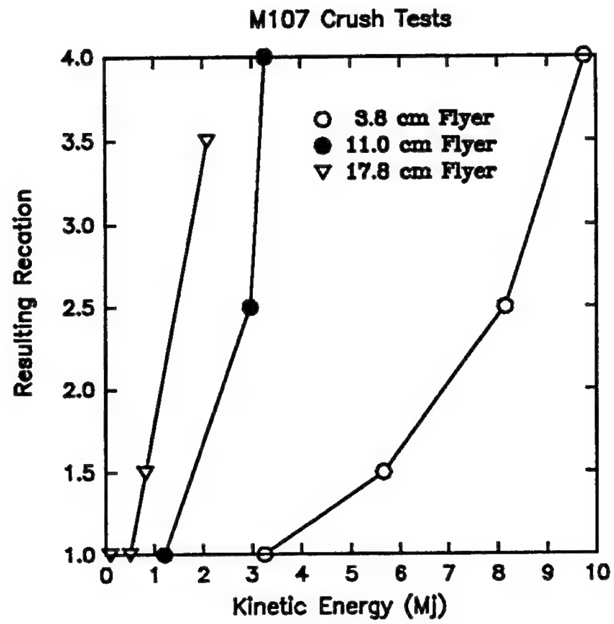

Figure 15. Plot of resulting reaction vs. flyer plate KE for M107 crush tests.

In Appendix A, figures showing the deformation of the M107s during no go and no go/partial burn reactions are shown. The dimensions on these figures are in inches and indicate the diameter of the projectile at various positions along the length. Measurements were taken in inch increments starting at the lifting eye and ending near the top of the rotating band. Figures 16 and 17 show typical fragment sizes from tests in which explosions occurred.

In Appendix B, examples of PVDF pressure-time histories are given. The fact that no time of arrival data is available at which the flyer plate impacts the first layer of the crush package makes it difficult to compare results from various tests. Figures B-4, B-5, and B-7 show the most realistic data obtained. The signals captured in these three plots are most likely the stress occurring during crushing of the round. In Figure B-5, the large negative portion of the graph is believed to be mechanical (release) unloading waves. No clear indications of when explosion or detonation events occurred can be seen in Figures B-4 and B-5. Lead failure and the fact that there are multiple load paths between the round and the anvil have greatly hindered the capture of good loading data. In our experimental setup, there are initially two load paths between the M107 and the anvil plate. These two load paths occur on the round at the rotating band and at the bourrelet. However, as the round deforms, the contact area between the round and the anvil grows

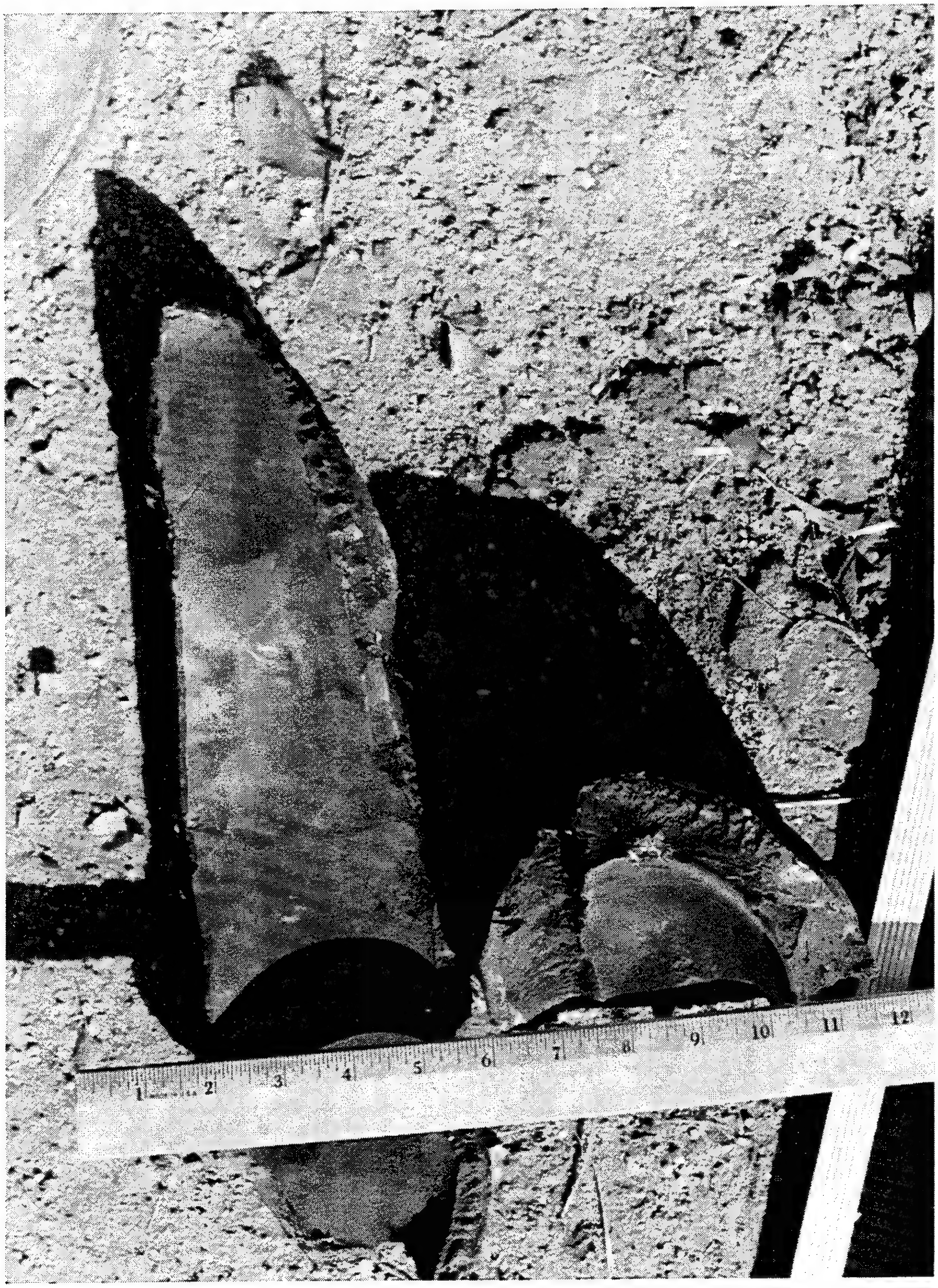

Figure 16. M107 fragments after an explosion.

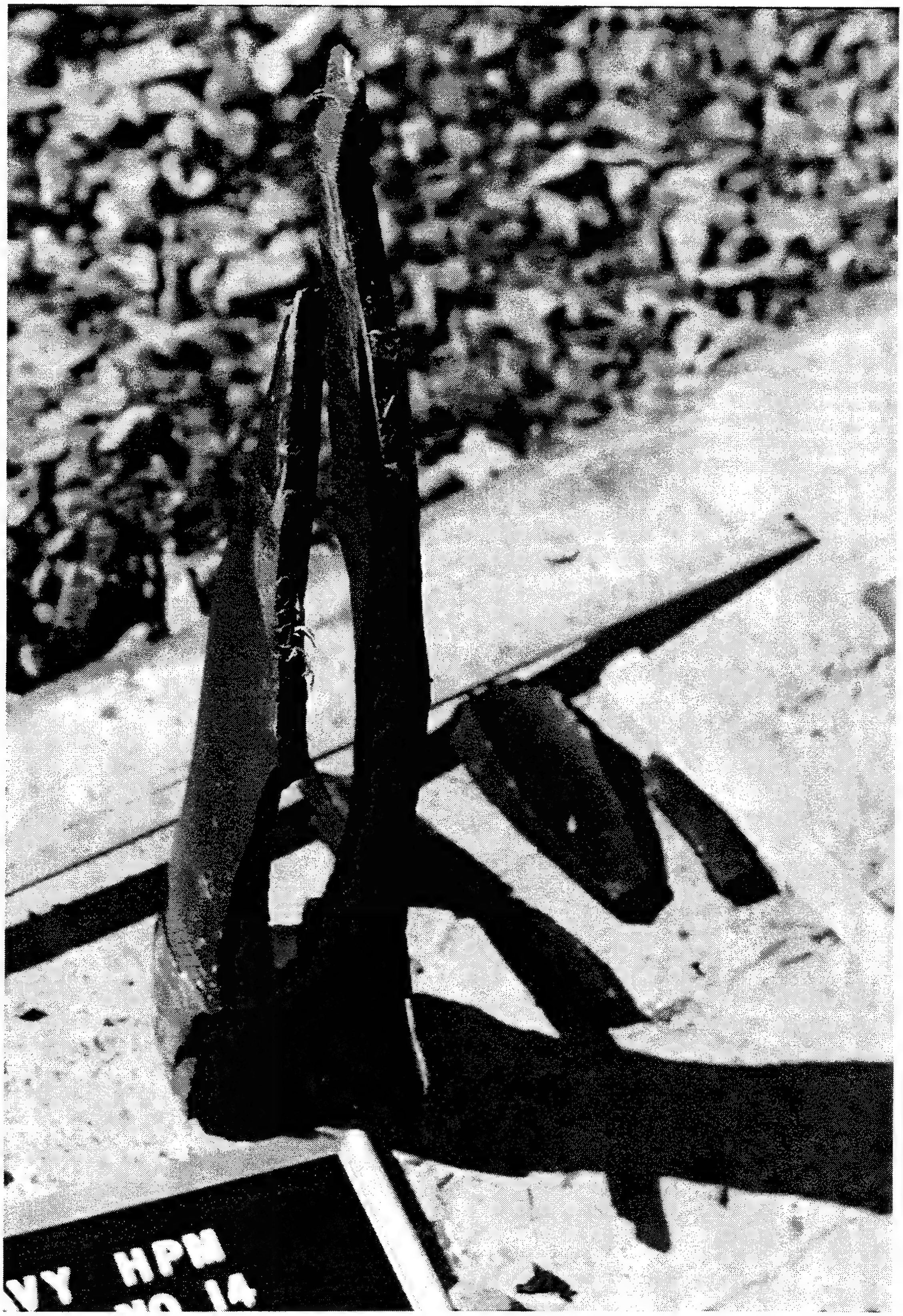

Figure 17. M107 fragments after test no. 14.

continuously. The increasing contact area makes the response of the PVDF change from the measurement of the load at one of the two load paths to a localized response at the specific point on the bourrelet where the gauge is located. Although most of the data collected is not very useful, it does show that PVDF can be used in this application. However, several modifications in instrumentation techniques must be used. In the next Section, some of these modifications will be addressed.

6. CONCLUSIONS AND RECOMMENDATIONS

Velocities at which no go, burn, explosion, and detonation events occur in TOW 2 warheads and in M107 artillery rounds for various flyer plate thicknesses have been found. Data obtained suggests that for lightly cased munitions such as the TOW 2 warhead, the level of reaction is closely related to the KE imposed on the round by the flyer plate. For heavily cased munitions such as the M107 artillery round, the level of reaction is closely related to the momentum of the impacting flyer plate.

PVDF gauges have provided some qualitative interface pressure data. However, to ensure good quantitative data in future tests of this type, a larger gauge in the load path between the round and anvil plate would be advisable. This would not only increase the gauge size (round dependent) but would drastically increase test costs. Longer lead lengths would solve circuitry impedance problems (by eliminating unnecessary transition wires and solder joints) and would ensure that the gauge not only survived the initial crushing of the round but would probably allow for the initial detection of explosion and detonation events. Time of arrival information of the flyer plate impacting the first polyethylene layer would aid in the interpretation of PVDF stress data and would allow for easier comparison between different tests.

Though the lessons learned in fixture design were not discussed during this report, a few comments on what was learned would be appropriate. Welds should be avoided if possible. Most welds survived no go and burn situations for the 3.8-cm and 11.0-cm shots but failed when the larger 17.8-cm-thick flyer plates were used. Lockable keys would probably have fared better than welds. The U-shaped stiffeners helped keep the frame catcher plates from splaying too much. The U-shaped stiffeners should have been attached to the baseplate by lockable keys instead of being welded to the baseplate. The welds on these stiffeners cracked during almost every test, which caused them to be removed midway through the testing to keep repair time to a minimum. Without the use of these stiffeners, the frame catchers started splaying, as was expected. The gussets used to minimize rotation and translation of the backstop worked well. A

spade on the fixture protruding some depth into the soil would have been useful in keeping rigid body motion of the fixture to a minimum. In tests were detonation events occurred, the fixture would sometimes translate back up to 15 m.

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MIL-STD-2105A (NAVY). "Hazard Assessment Tests for Non-Nuclear Munitions." 8 March 1991.

Yadav, H. S. "Flyer Plate Motion by Thin Sheet of Explosive." Propellants, Explosives, Pyrotechnics, vol. 13, pp. 17–20, 1988.

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APPENDIX A:

DEFORMED M107 SCHEMATICS

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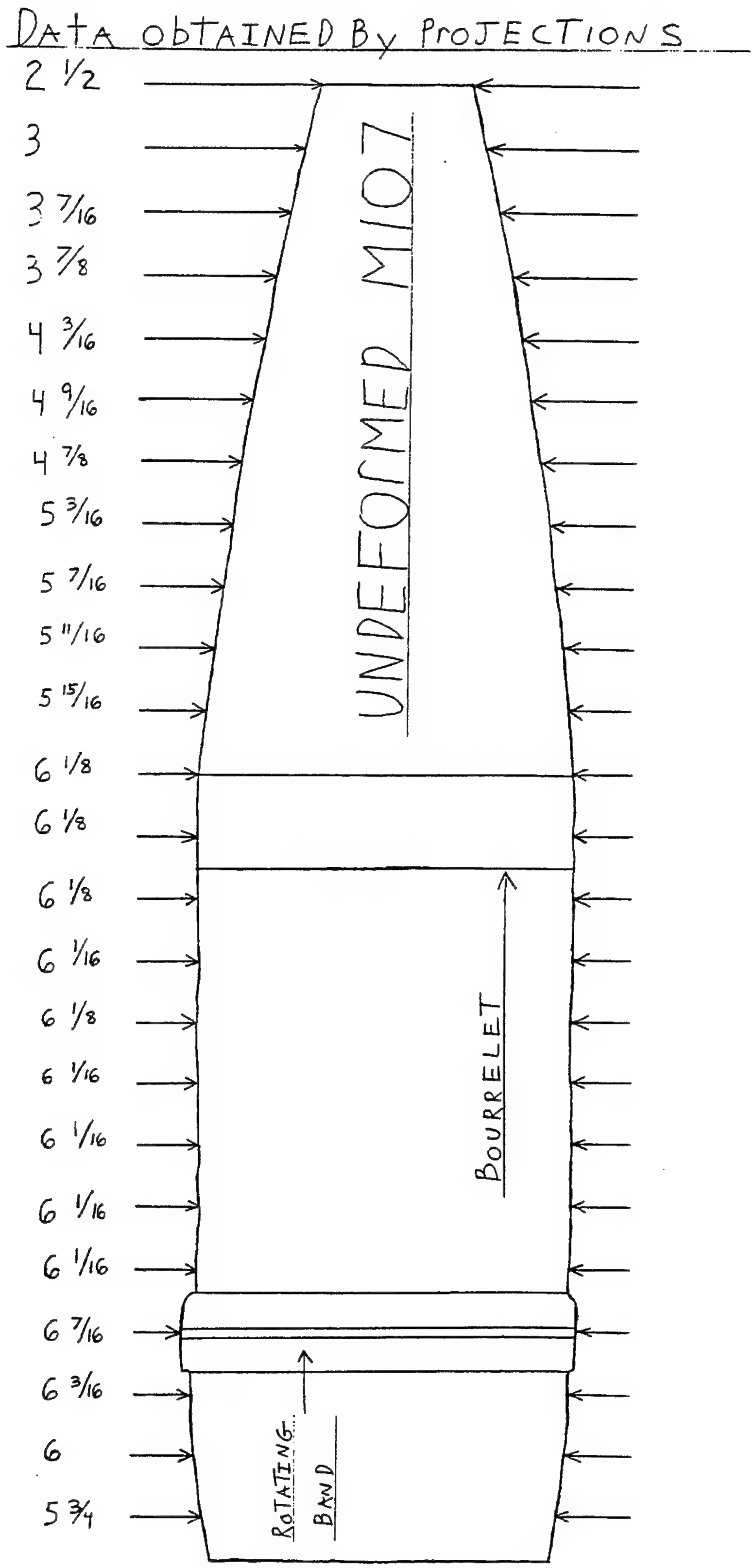

Figure A-1. Schematic of undeformed M107 round.

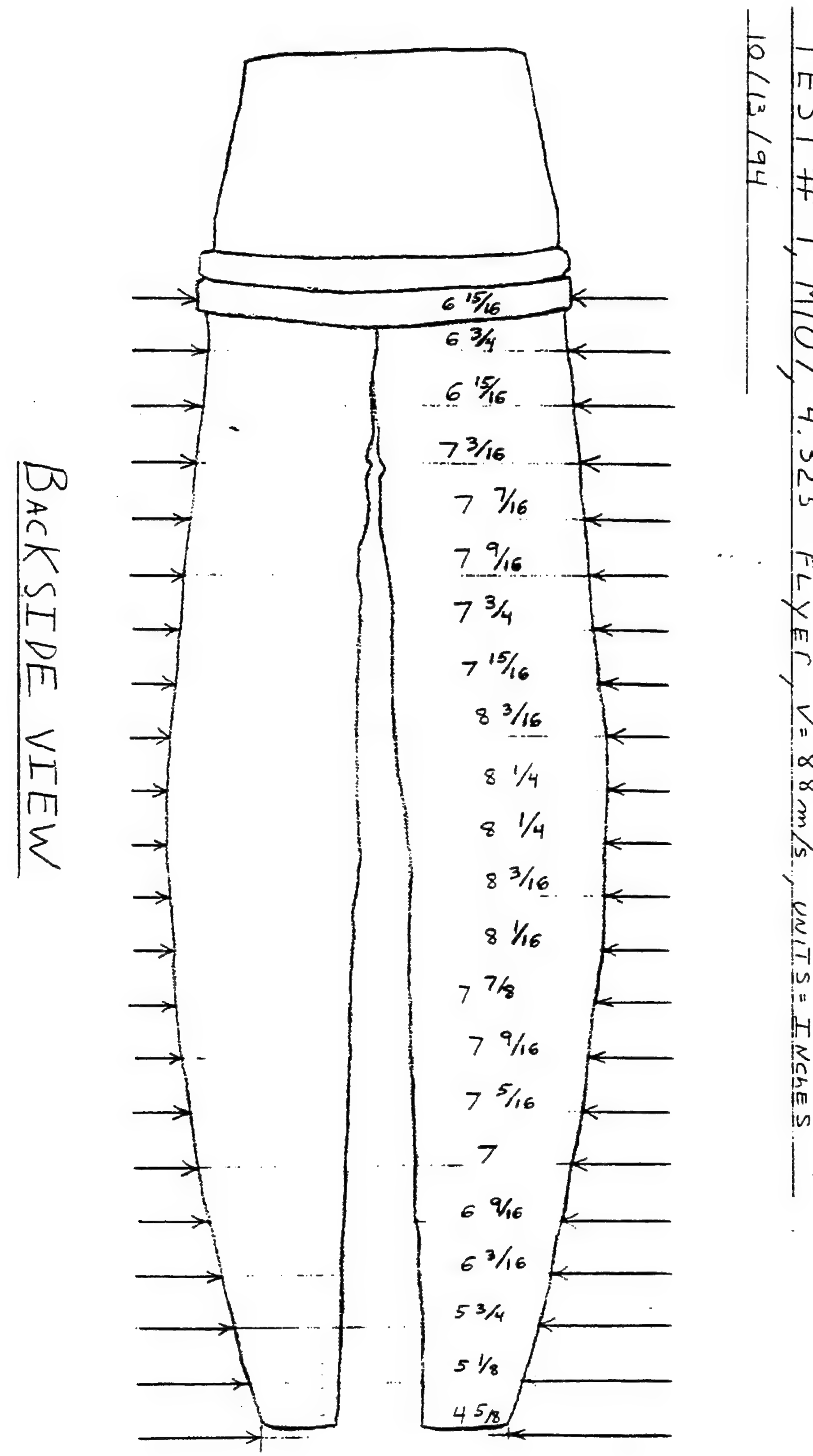

Figure A-2. Schematic of deformed M107 round after test no. 9 (back side view, facing anvil).

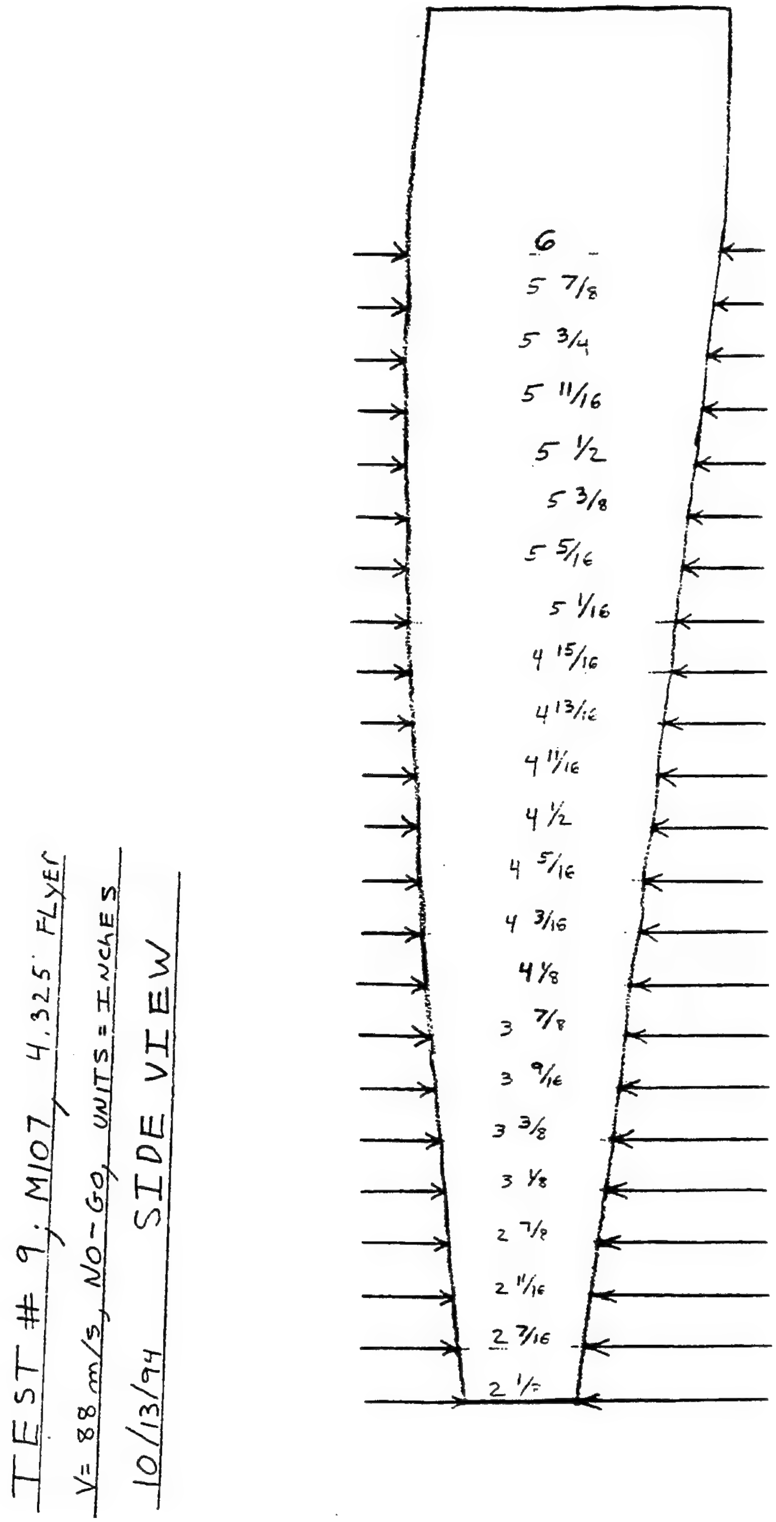

Figure A-3. Schematic of deformed M107 round after test no. 9 (side view).

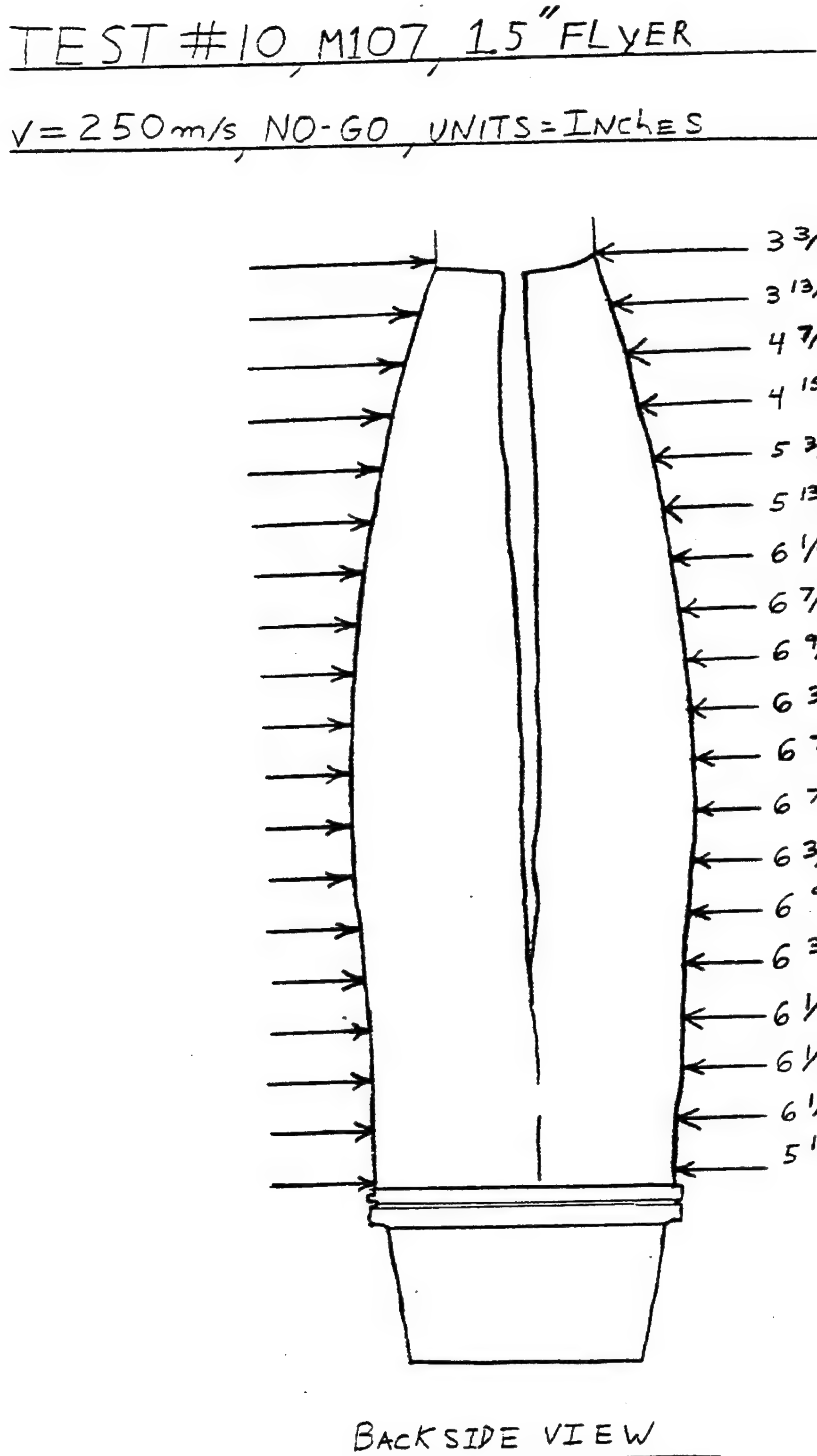

Figure A-4. Schematic of deformed M107 round after test no. 10 (back side view, side facing anvil).

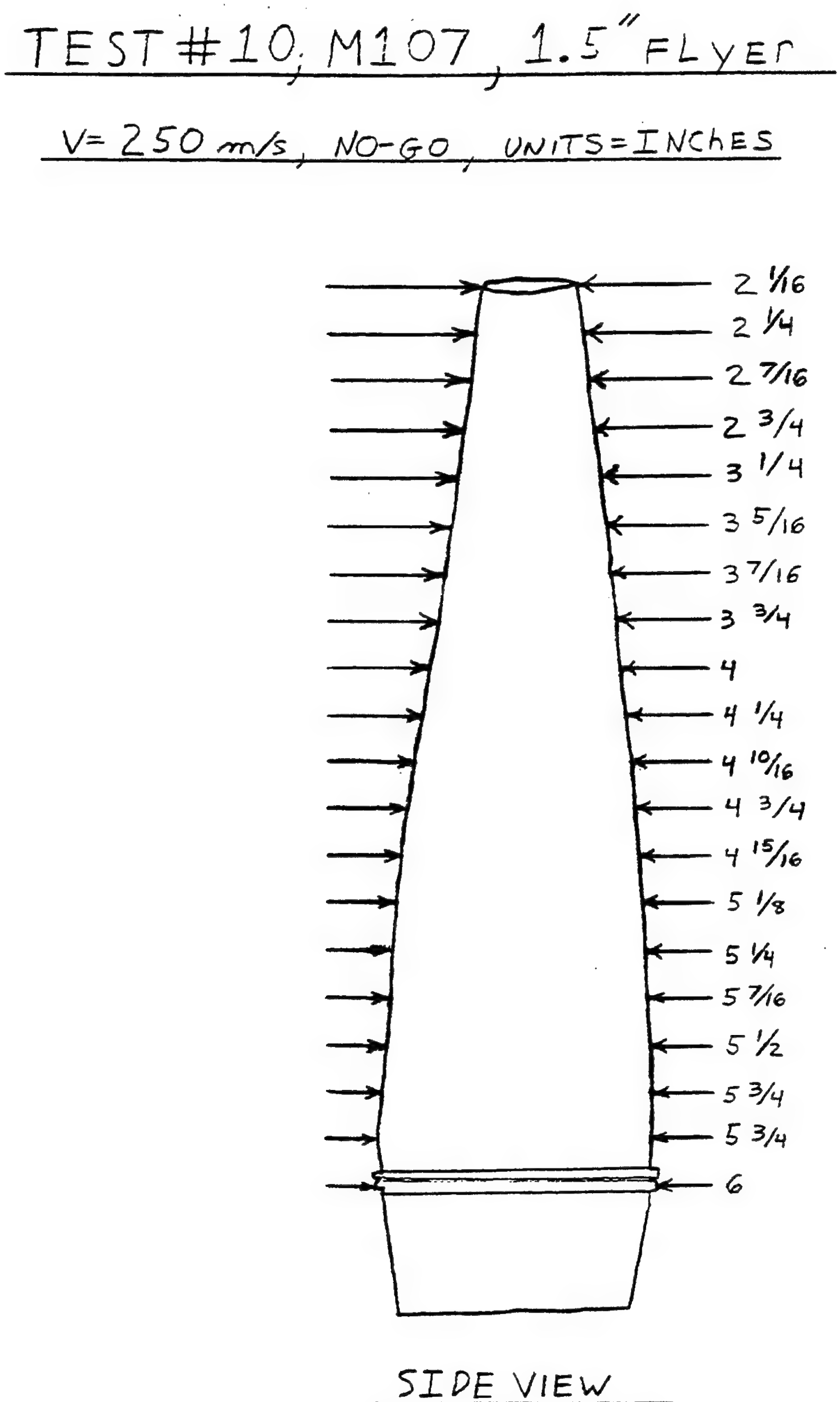

Figure A-5. Schematic of deformed M107 round after test no. 10 (side view).

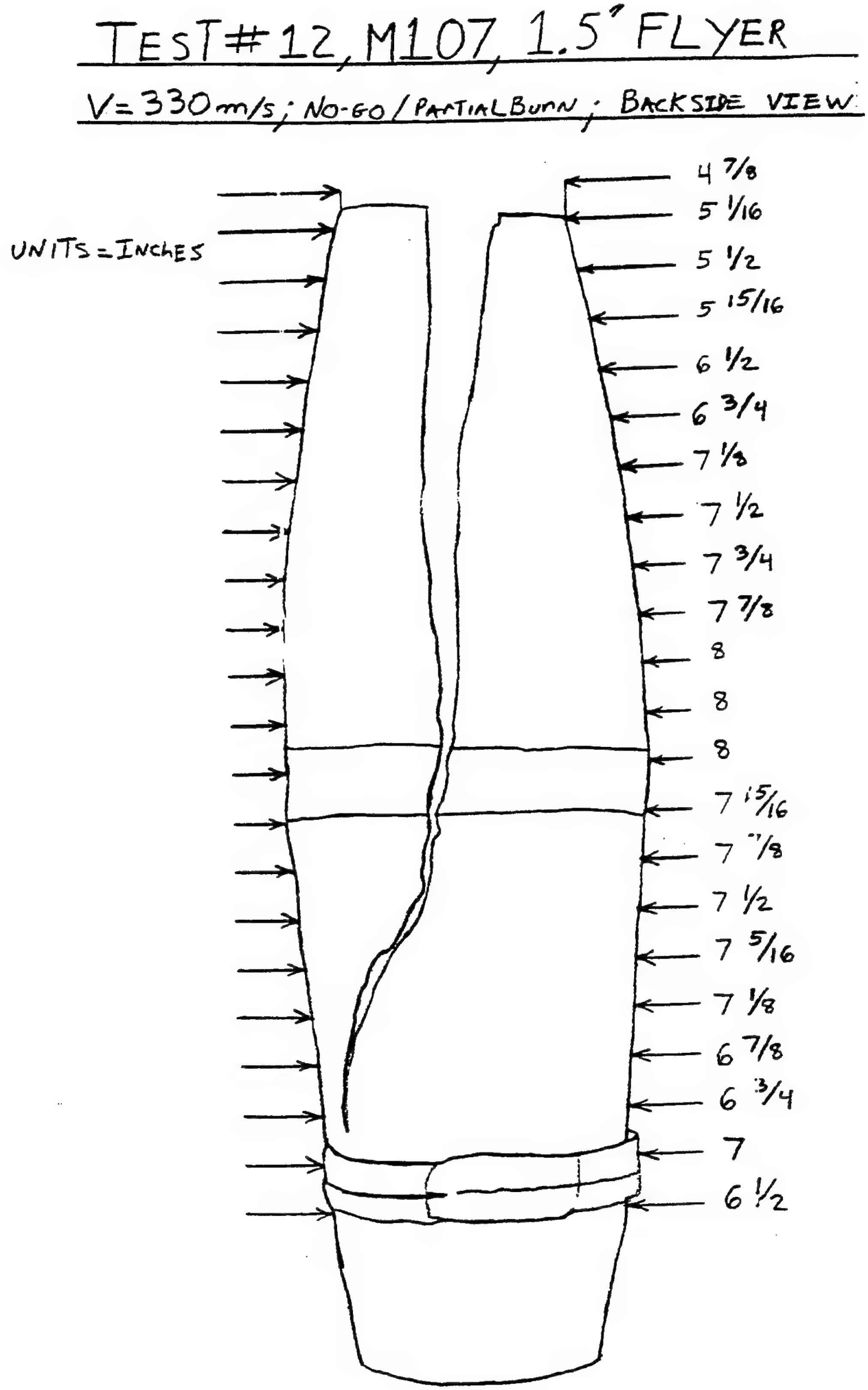

Figure A-6. Schematic of deformed M107 round after test no. 12 (back side view, side facing anvil).

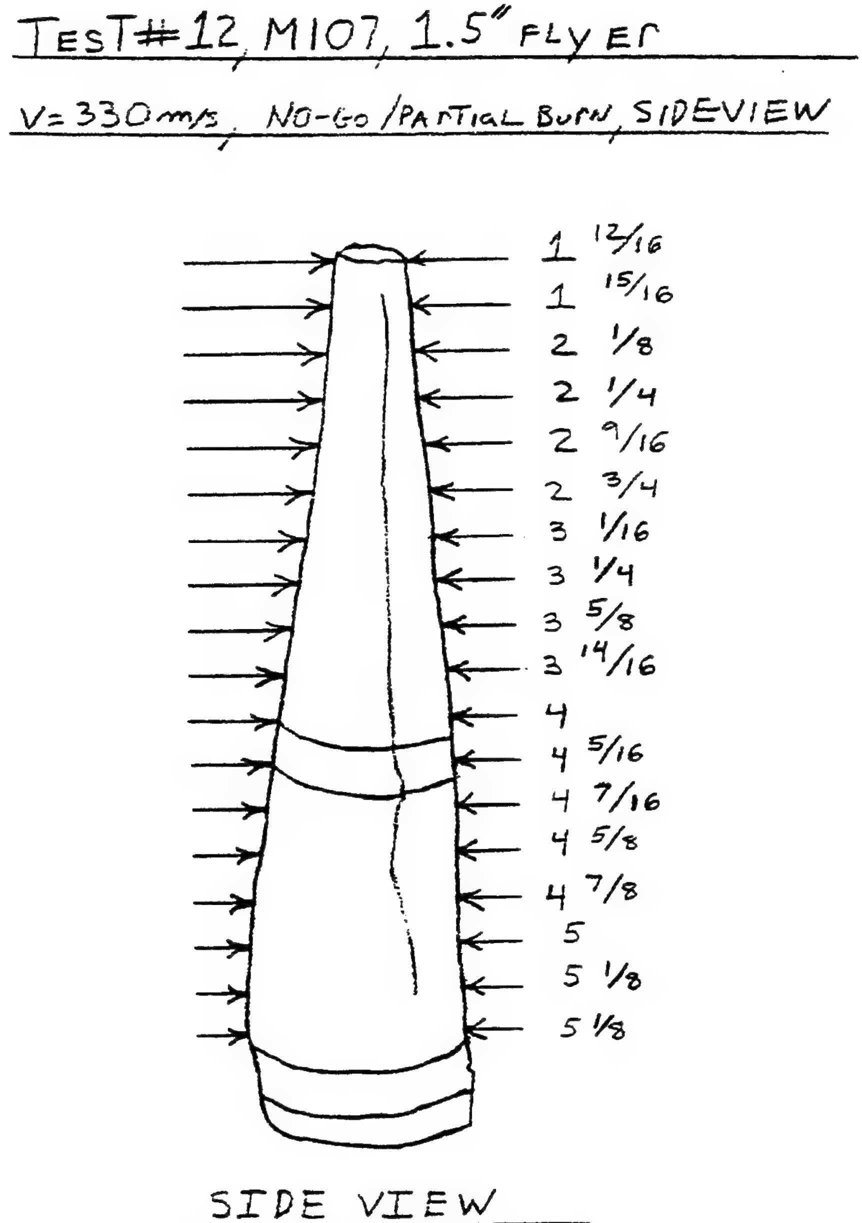

Figure A-7. Schematic of deformed M107 round after test no. 12 (side view).

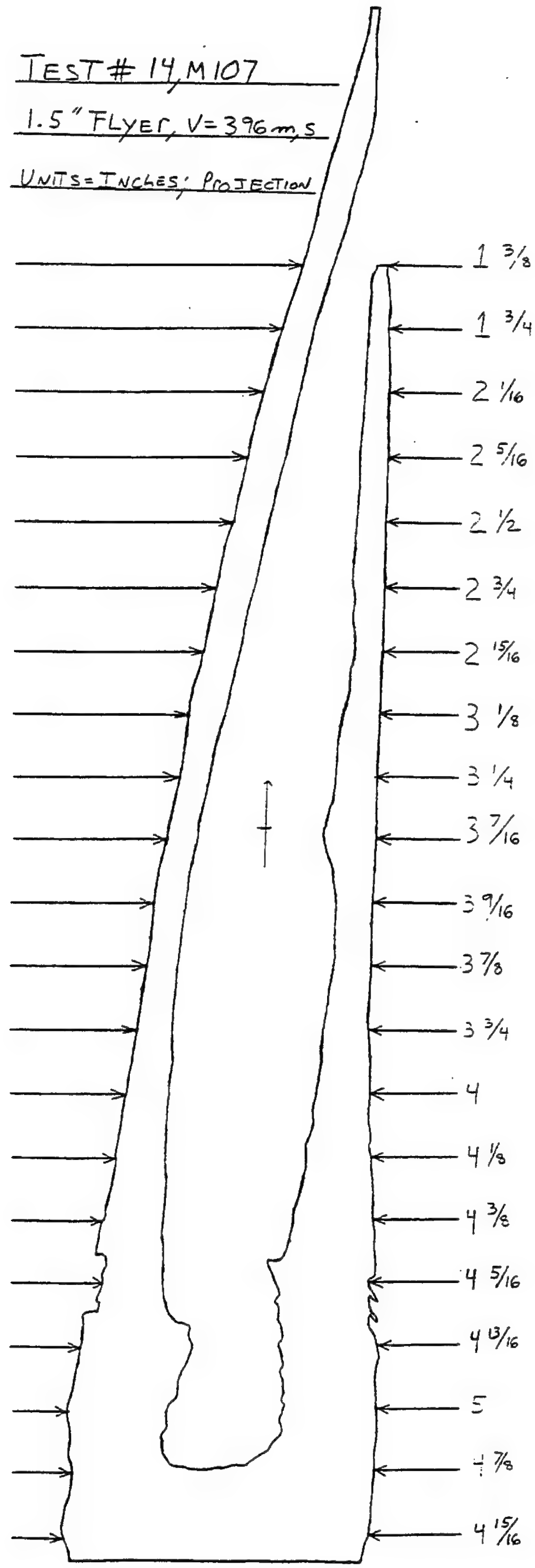

Figure A-8. Schematic of deformed M107 round after test no. 14 (projection).

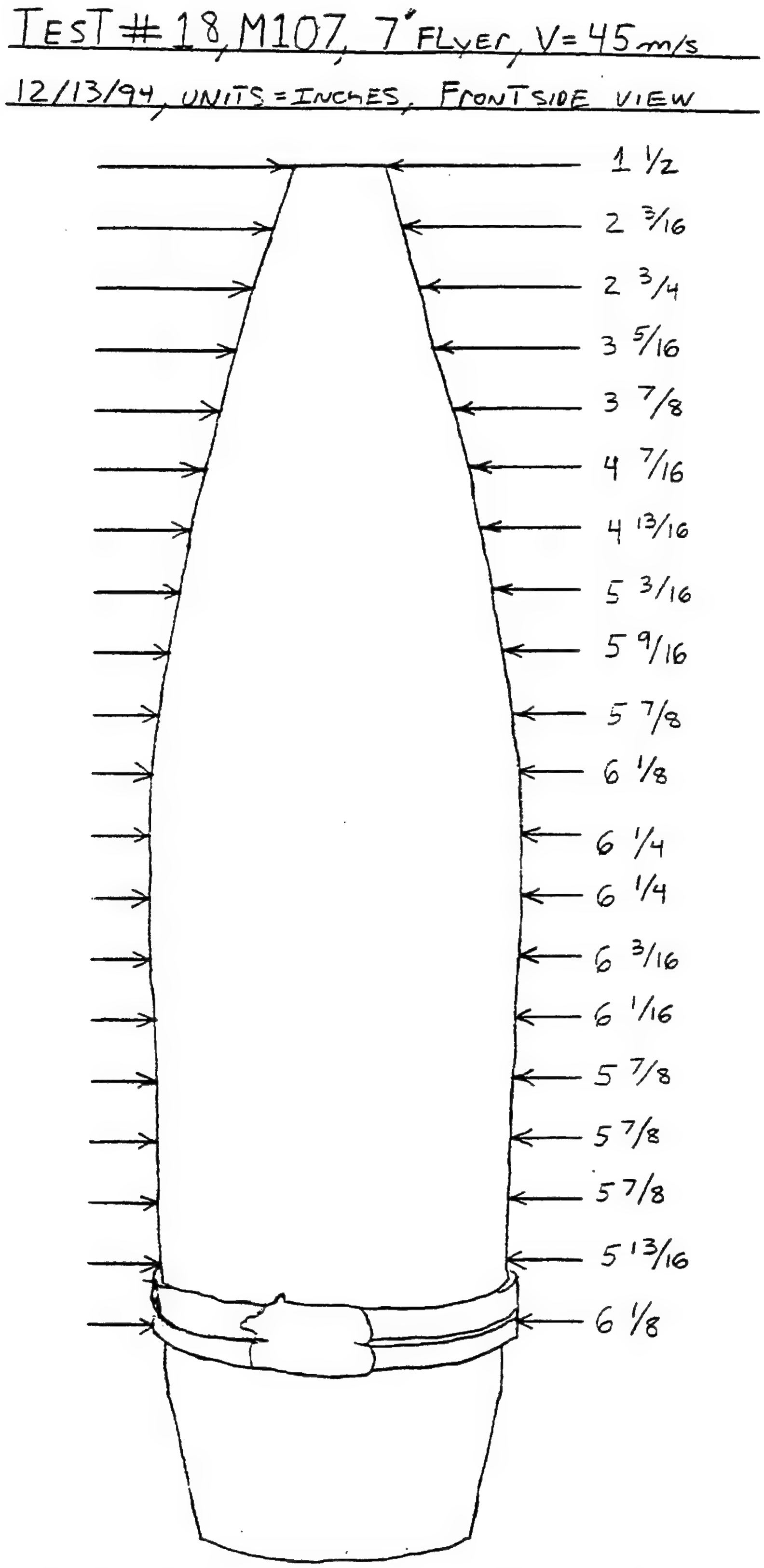

Figure A-9. Schematic of deformed M107 round after test no. 18 (front side view, side facing flyer plate).

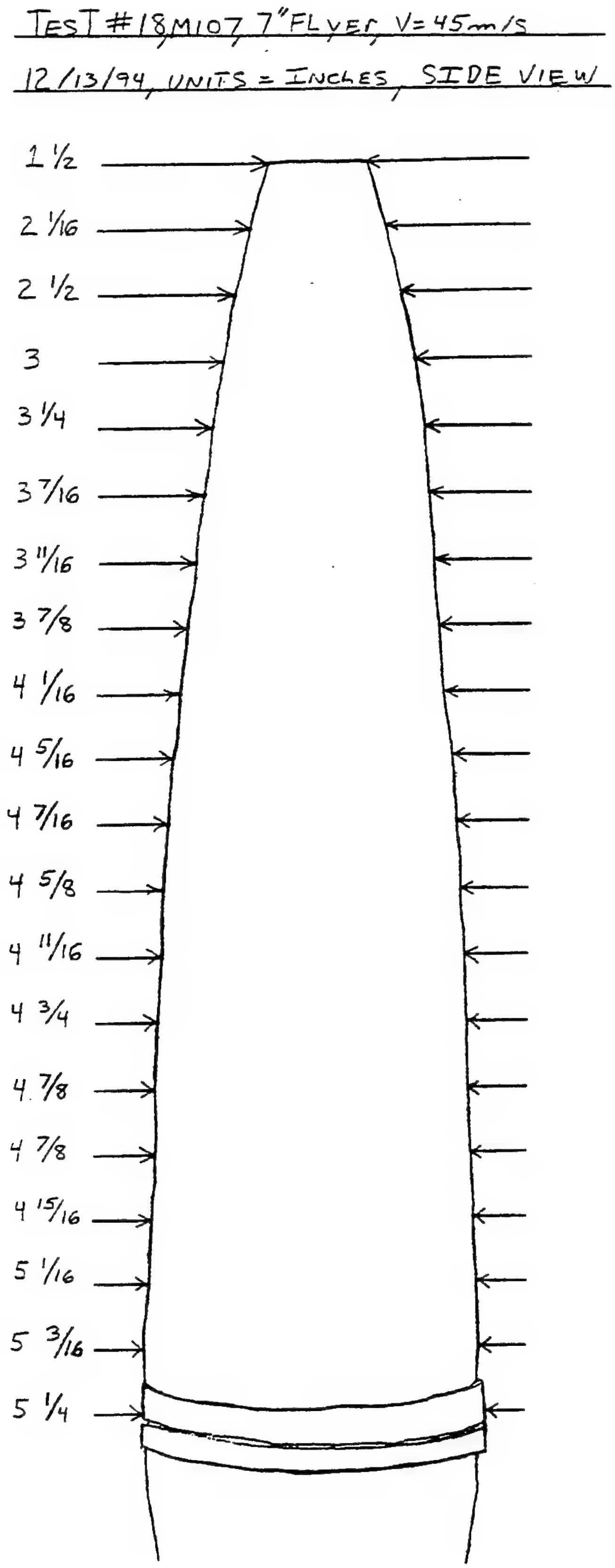

Figure A-10. Schematic of deformed M107 round after test no. 18 (side view).

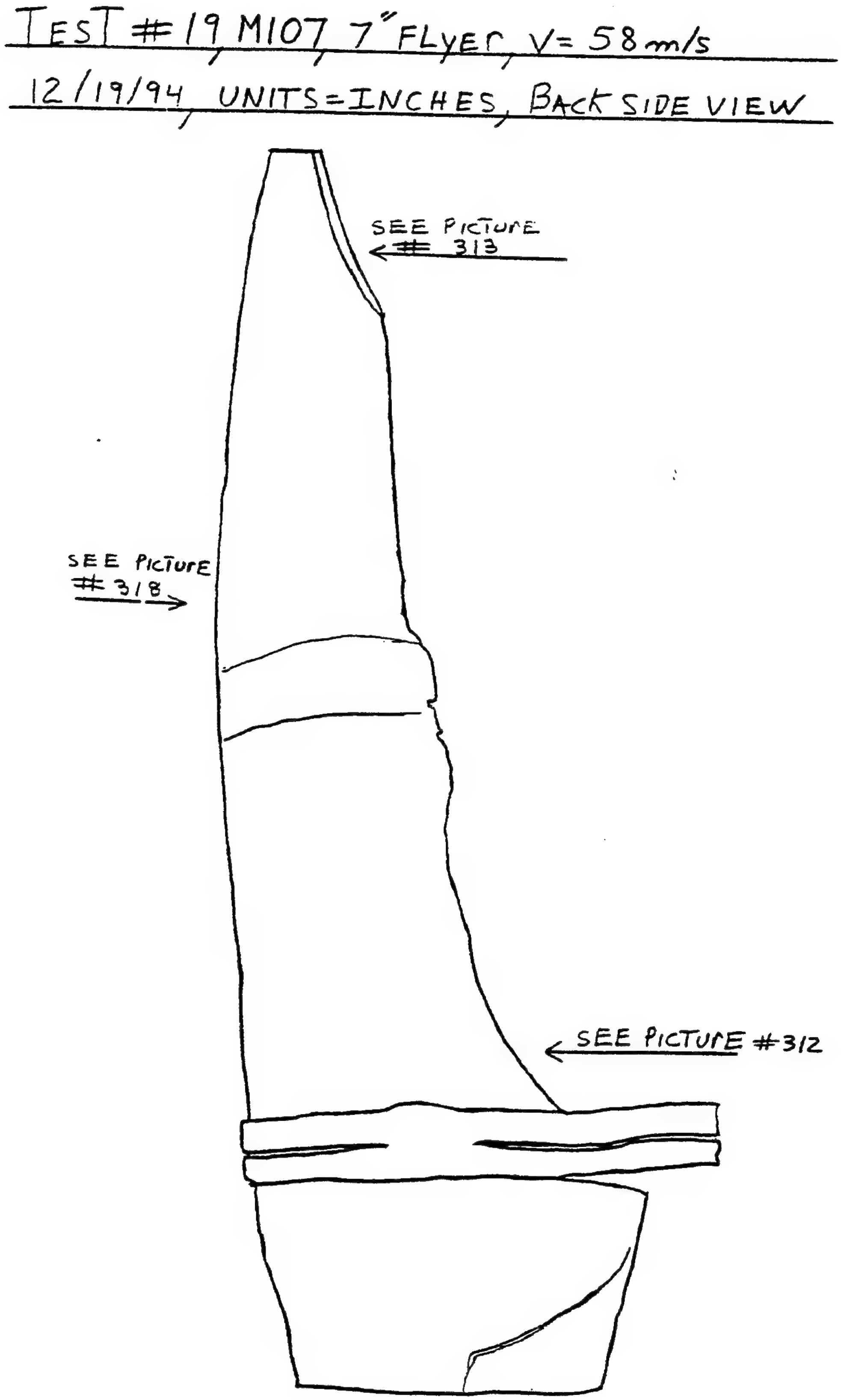

Figure A-11. Schematic of deformed M107 round after test no. 19 (back side view).

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APPENDIX B:

PVDF TIME HISTORIES

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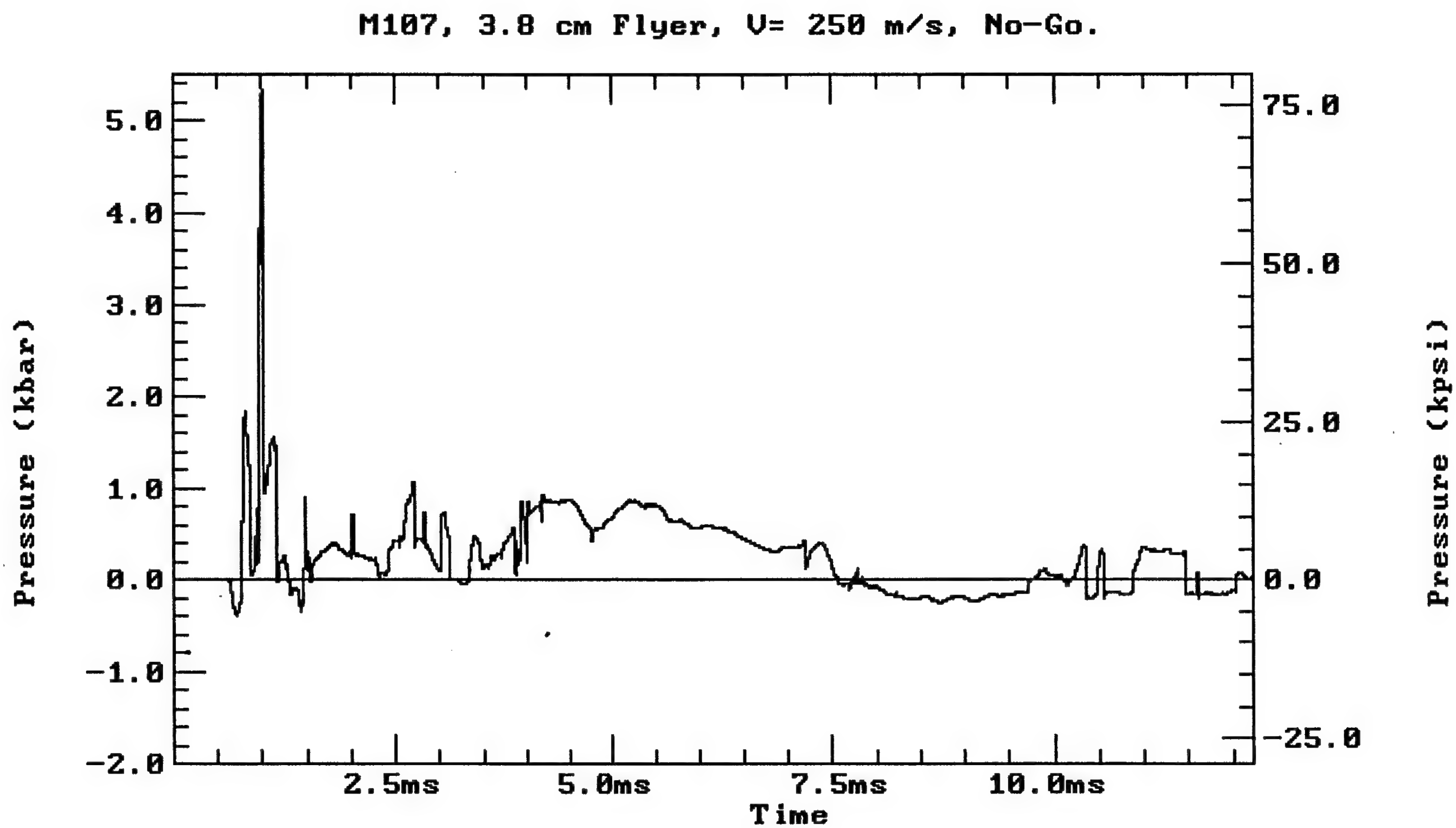

Figure B-1. PVDF time history for test no. 10.

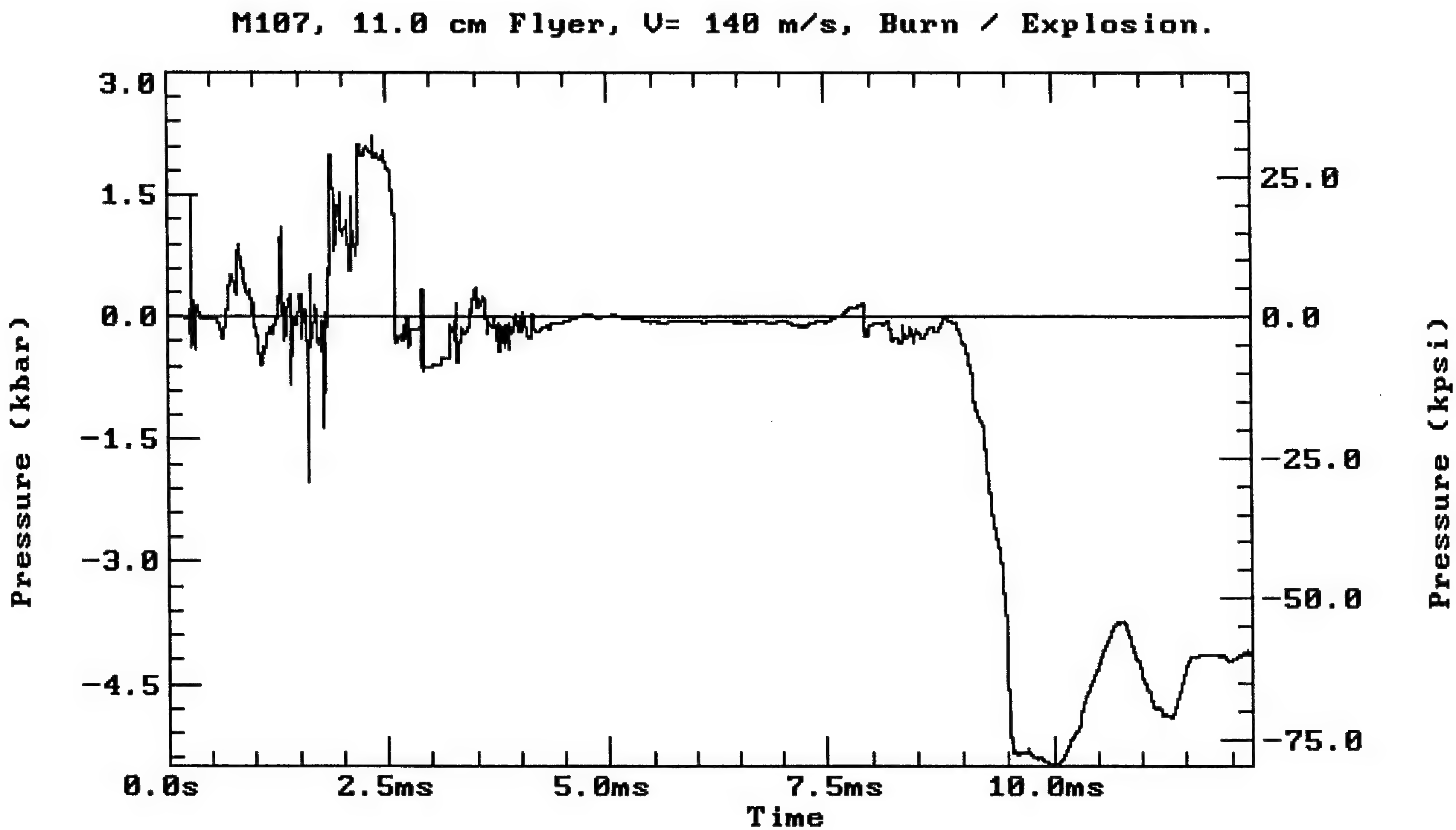

Figure B-2. PVDF time history for test no. 11.

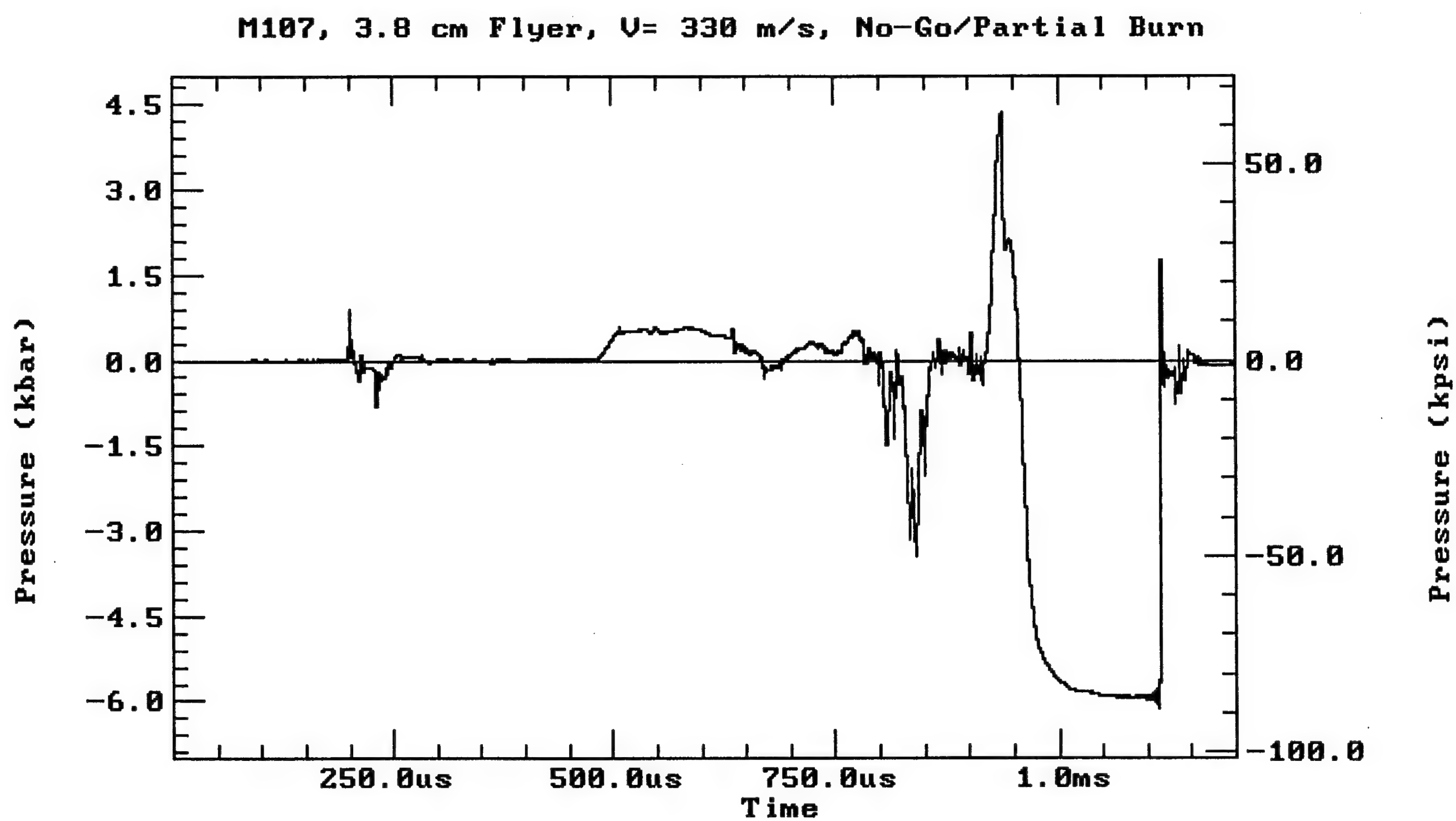

Figure B-3. <u>PVDF time history for test no. 12</u>.

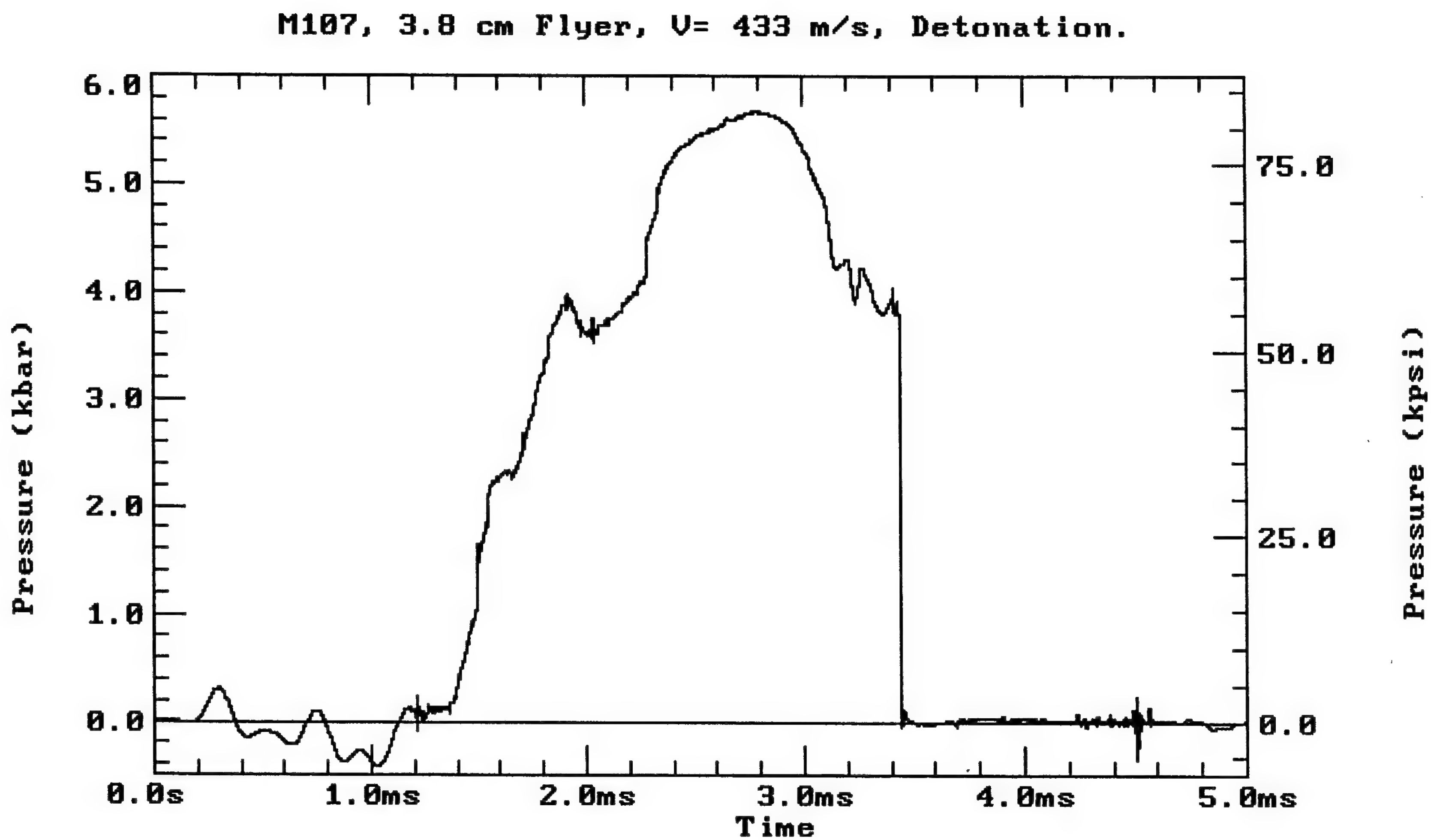

Figure B-4. PVDF time history for test no. 13.

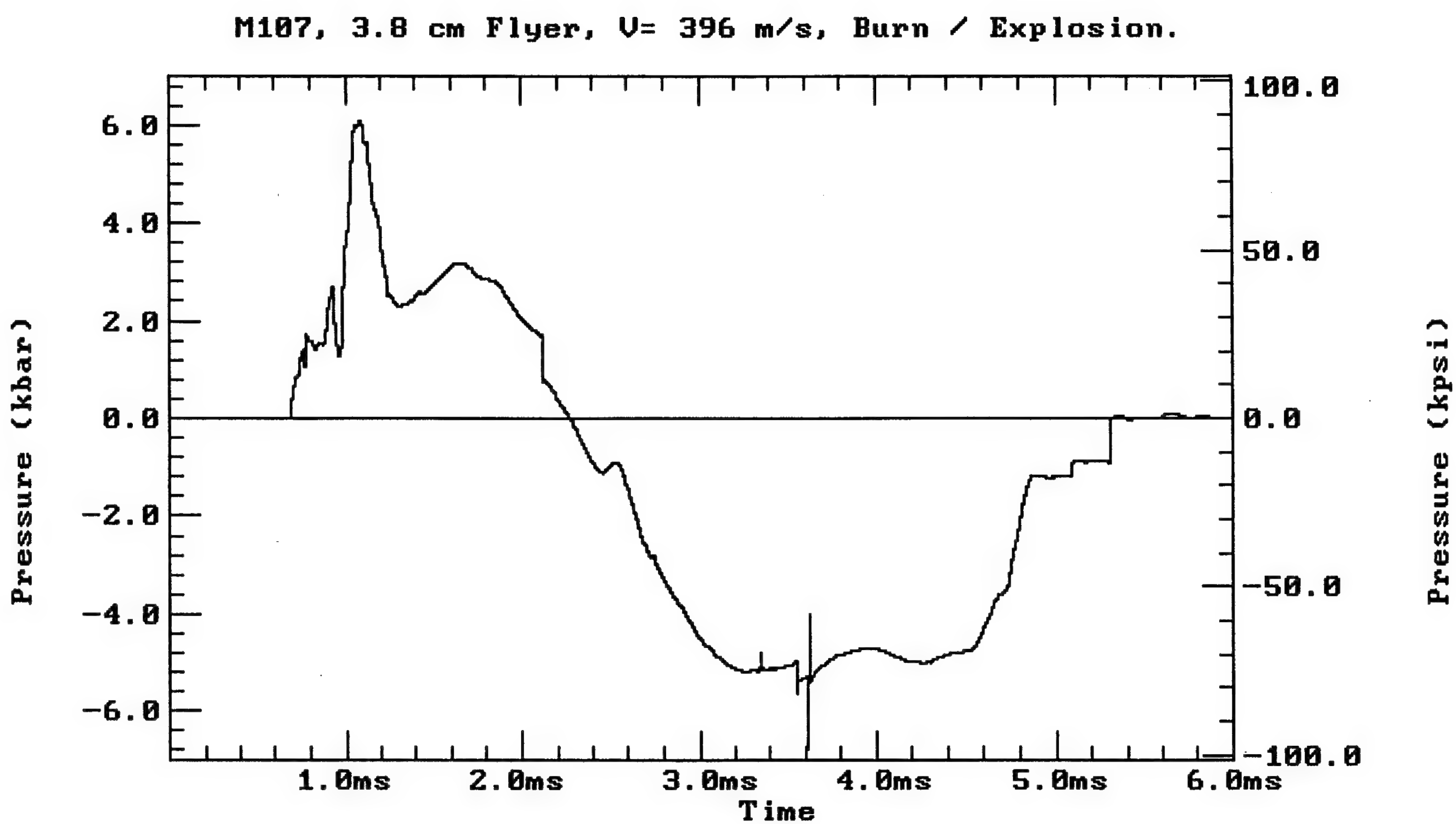

Figure B-5. PVDF time history for test no. 14.

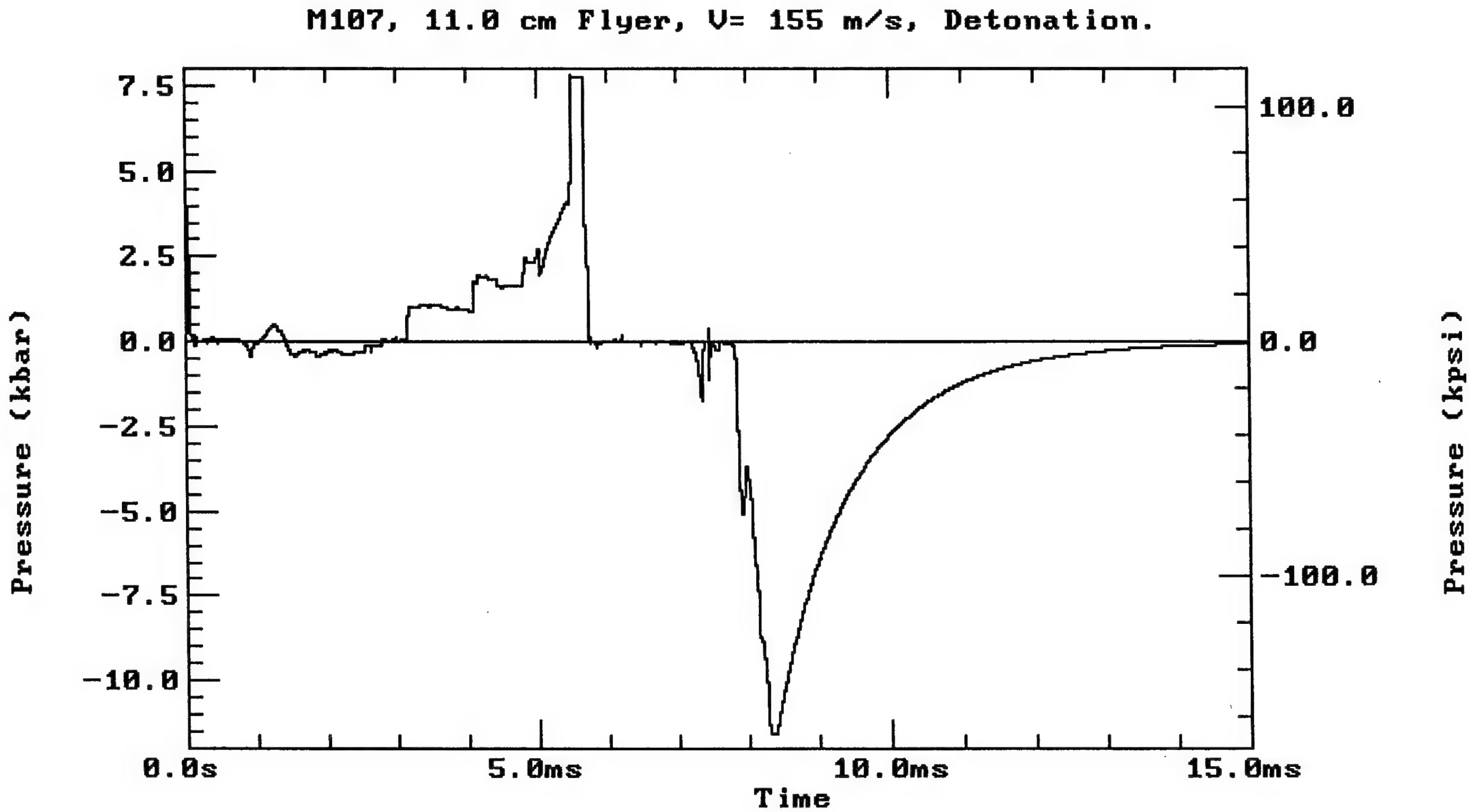

Figure B-6. PVDF time history for test no. 15.

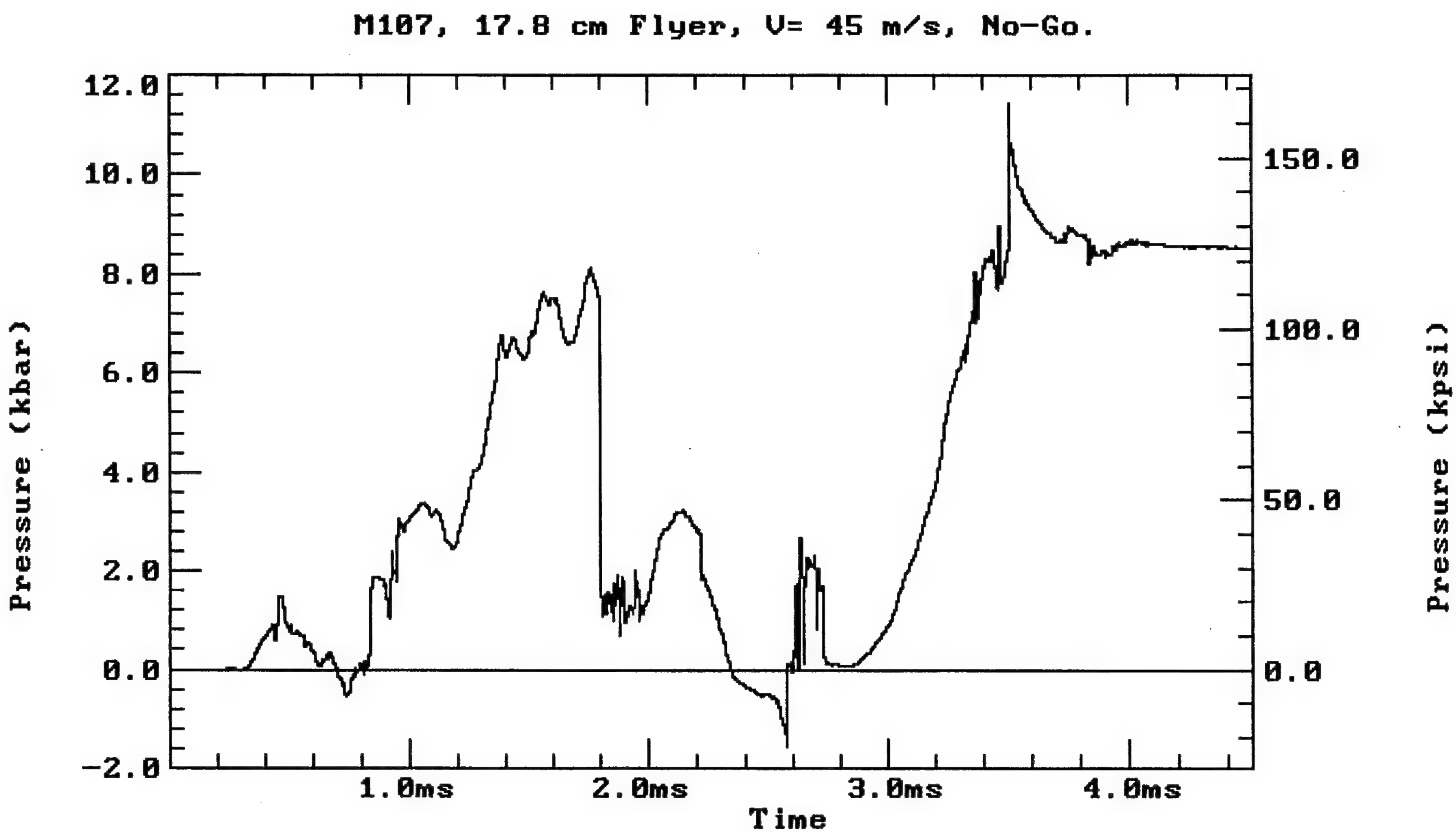

Figure B-7. PVDF time history for test no. 18.

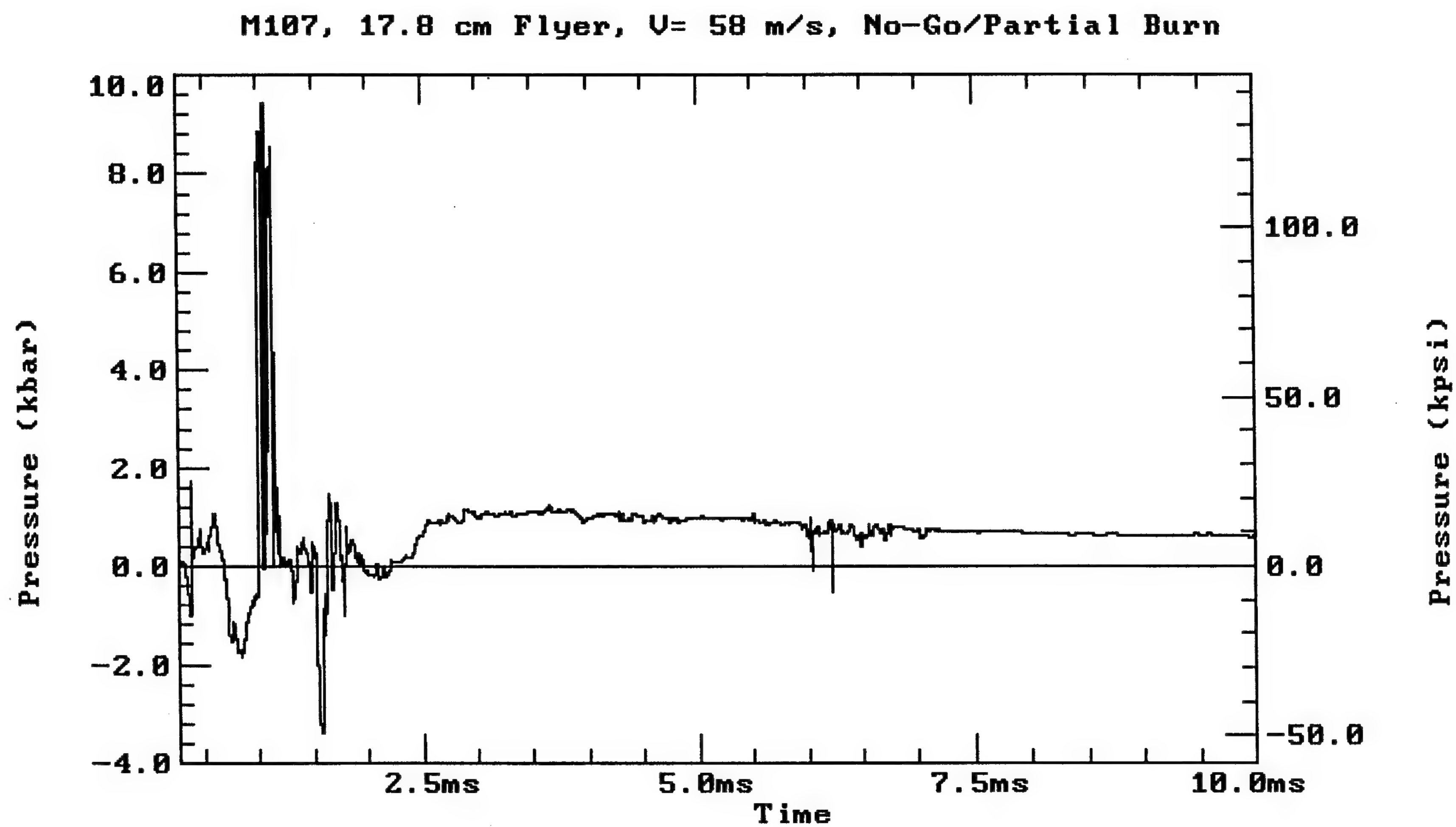

Figure B-8. PVDF time history for test no. 19.

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